AL.2.1992-13




ENVIRONMENTAL MANAGEMENT ASSOCIATES

PHILLIP M. ULLMAN, P.ENG.
DAVID A. FERNET, M.SC.
DONALD A. YOUNG, M.SC.
DAVID S. KERR, M.SC.

1510 TENTH AVENUE S.W.
CALGARY, ALBERTA, CANADA
T3C 0J5
TELEPHONE (403) 245-1623
FACSIMILE (403) 245-6634

CANADIANA

DEC 30 1991

# INSTREAM FLOW REQUIREMENTS FOR FISHES DOWNSTREAM OF THE OLDMAN RIVER DAM

Prepared for:

Alberta Public Works, Suppy and Services
Oldman River Dam Project
Edmonton, Alberta

Prepared by:

D.A. Fernet, R.F. Courtney and C.P. Bjornson
Environmental Management Associates
Calgary, Alberta

May, 1990

National Library of Canada Bibliothèque nationale du Canada

EMA ENVIRONMENTAL MANAGEMENT ASSOCIATES

PHILLIP M. ULLMAN, P.ENG.
DAVID A. FERNET, M.SC.
DONALD A. YOUNG, M.SC.
DAVID S. KERR, M.SC.

1510 TENTH AVENUE S.W.
CALGARY, ALBERTA, CANADA
T3C 0J5
TELEPHONE (403) 245-1623
FACSIMILE (403) 245-6634

# INSTREAM FLOW REQUIREMENTS FOR FISHES DOWNSTREAM OF THE OLDMAN RIVER DAM

Prepared for:

Alberta Public Works, Suppy and Services
Oldman River Dam Project
Edmonton, Alberta

Prepared by:

D.A. Fernet, R.F. Courtney and C.P. Bjornson
Environmental Management Associates
Calgary, Alberta

May, 1990


Digitized by the Internet Archive
in 2016

https://archive.org/details/instreamflowrequ00fern

# INSTREAM FLOW REQUIREMENTS FOR FISHES DOWNSTREAM OF THE OLDMAN RIVER DAM

Prepared for:

Alberta Public Works, Suppy and Services
Oldman River Dam Project
Edmonton, Alberta

Prepared by:

D.A. Fernet, R.F. Courtney and C.P. Bjornson
Environmental Management Associates
Calgary, Alberta

May, 1990

# TABLE OF CONTENTS

TABLE OF CONTENTS . . . . . i
LIST OF TABLES . . . . . ii
LIST OF FIGURES . . . . . iv

1.0 EXECUTIVE SUMMARY . . . . . 1

2.0 INTRODUCTION . . . . . 5

3.0 TERMS OF REFERENCE . . . . . 11

4.0 APPROACH . . . . . 14

5.0 METHODS . . . . . 17
5.1 COLLECTION OF LOW FLOW HYDRAULIC DATA . . . . . 17
5.2 DEVELOPMENT OF HABITAT PREFERENCE INFORMATION . . 18
5.2.1 Collection of Habitat Availability Hydraulic Data . . . . . 19
5.2.1.1 Bow River . . . . . 25
5.2.1.2 Oldman River . . . . . 28
5.2.1.3 Crowsnest River . . . . . 30
5.2.2 Collection of Habitat Utilization Data . . 32
5.2.2.1 Bow River . . . . . 36
5.2.2.2 Oldman River . . . . . 39
5.2.2.3 Crowsnest River . . . . . 48
5.2.3 Qualitative Rating of Habitat Utilization Data . . . . . 51
5.2.4 Quantitative Rating of Habitat Utilization Data . . . . . 54
5.2.5 Development of Habitat Preference Curves . 60
5.2.6 Transferability of Walleye and Sauger Preference Criteria . . . . . 62
5.3 ANALYSIS OF HABITAT AVAILABILITY WITH DISCHARGE IN THE OLDMAN RIVER . . . . . 62
5.4 IDENTIFICATION OF INSTREAM FLOW NEEDS FOR FISH . 64
5.4.1 Methodology . . . . . 64
5.4.2 Analysis of Habitat Availability . . . . . 67
5.5 FACTORS LIMITING FISHERY PRODUCTIVITY AND MITIGATION MEASURES . . . . . 72
5.6 FLUSHING FLOW REQUIREMENTS . . . . . 74
5.7 WATER QUALITY . . . . . 75

6.0 RESULTS . . . . . 76
6.1 LOW FLOW MEASUREMENTS . . . . . 76
6.2 HABITAT PREFERENCE CRITERIA . . . . . 76
6.2.1 Habitat Preference Curve Development . . . 76
6.2.2 Transferability of Habitat Preference Curves . . . . . 96
6.3 HABITAT AVAILABILITY AS A FUNCTION OF STREAMFLOW 97

**TABLE OF CONTENTS (Concluded)**

6.4 IDENTIFICATION OF INSTREAM FLOWS FOR FISH . . . . 113
6.4.1 Software Development . . . . . 113
6.4.2 Instream Flow Requirements For Fish . . . 113
6.4.3 Habitat Availability Under Various Flow Regimes . . . . . 118
6.4.4 Flushing Flow Requirements . . . . . 121

7.0 DISCUSSION . . . . . 129
7.1 EVALUATION OF WATER BALANCE SIMULATIONS . . . . . 129
7.2 EFFECTS OF FLOW REGULATION ON HABITAT AVAILABILITY . . . . . 132

8.0 REFERENCES CITED . . . . . 133

APPENDIX I An examination of the transferability of habitat preference criteria, rainbow trout and brown trout.

APPENDIX II Evaluation of sample size requirements for the development of habitat preference criteria.

APPENDIX III An assessment of habitat enhancement structures which are under consideration for project mitigation.

APPENDIX IV Data sets used in the development of habitat preference criteria.

## LIST OF TABLES

PAGE

TABLE 1 SUBSTRATE DEFINITIONS AND SIZE-RANGE CATEGORIES ..... 23

TABLE 2 COVER-TYPE CODINGS, DEFINITIONS AND FUNCTIONS ..... 24

TABLE 3 FORK LENGTH CATEGORIZATION OF LIFE STAGES EMPLOYED IN THIS STUDY..... 37

TABLE 4 QUALITY RATING OF THE UTILIZATION DATA FOR THE CROWSNEST, BOW AND OLDMAN RIVER STUDY REACHES, 1988 ..... 52

TABLE 5 ACTUAL AND CALCULATED SAMPLE SIZES FOR DEPTH, VELOCITY AND SUBSTRATE UTILIZATION VARIABLES..... 57

TABLE 6 RECORDED, NATURALIZED AND SIMULATED FLOW RECORDS EMPLOYED IN ANALYZING HABITAT DURATIONS, OLDMAN RIVER..... 68

TABLE 7 WEIGHTINGS EMPLOYED IN DEVELOPING THE HABITAT VERSUS FLOW RELATIONSHIP FOR THE COMPOSITE FISH ..... 71

TABLE 8 IDEAL FISH RULE CURVES FOR EACH RIVER SEGMENT ..... 116

TABLE 9 RECOMMENDED FISH RULE CURVES FOR INTEGRATED RIVER SEGMENTS ..... 119

TABLE 10 A RELATIVE COMPARISON OF HABITAT AVAILABILITY FOR THE NATURAL, RECORDED AND ODO5 FLOW REGIMES ..... 127

## LIST OF FIGURES


| | | PAGE |
|---|---|---|
| FIGURE 1 | STUDY AREA ..... | 6 |
| FIGURE 2 | OLDMAN RIVER INSTREAM FLOW STUDY AREA ..... | 7 |
| FIGURE 3 | LOCATION OF BOW RIVER STUDY REACH, 1988 .... | 26 |
| FIGURE 4 | LOCATION OF OLDMAN RIVER (GRAND FORKS) STUDY REACH, 1988 ..... | 29 |
| FIGURE 5 | LOCATION OF CROWSNEST RIVER STUDY REACH, 1988 ..... | 31 |
| FIGURE 6 | LOCATIONS OF BOAT ELECTROFISHER SAMPLING, WALLEYE AND SAUGER SPAWNING STUDY, 1988 .... | 40 |
| FIGURE 7 | LOCATIONS OF BOAT ELECTROFISHER SAMPLING FOR WALLEYE AND SAUGER FRY, 1988 ..... | 49 |
| FIGURE 8 | BROWN TROUT FRY HABITAT PREFERENCE CURVES .. | 77 |
| FIGURE 9 | BROWN TROUT JUVENILE HABITAT PREFERENCE CURVES ..... | 78 |
| FIGURE 10 | BROWN TROUT ADULT HABITAT PREFERENCE CURVES. | 79 |
| FIGURE 11 | BROWN TROUT SPAWNING HABITAT PREFERENCE CURVES ..... | 80 |
| FIGURE 12 | RAINBOW TROUT FRY HABITAT PREFERENCE CURVES. | 81 |
| FIGURE 13 | RAINBOW TROUT JUVENILE HABITAT PREFERENCE CURVES ..... | 82 |
| FIGURE 14 | RAINBOW TROUT ADULT HABITAT PREFERENCE CURVES ..... | 83 |
| FIGURE 15 | RAINBOW TROUT SPAWNING HABITAT PREFERENCE CURVES ..... | 84 |
| FIGURE 16 | SAUGER FRY HABITAT PREFERENCE CURVES ..... | 85 |
| FIGURE 17 | SAUGER JUVENILE HABITAT PREFERENCE CURVES .. | 86 |

## LIST OF FIGURES (Continued ...)


| | | |
|---|---|---|
| FIGURE 18 | SAUGER ADULT HABITAT PREFERENCE CURVES ..... | 87 |
| FIGURE 19 | SAUGER SPAWNING HABITAT PREFERENCE CURVES .. | 88 |
| FIGURE 20 | WALLEYE FRY HABITAT PREFERENCE CURVES ..... | 90 |
| FIGURE 21 | WALLEYE JUVENILE (DAY) HABITAT PREFERENCE CURVES ..... | 91 |
| FIGURE 22 | WALLEYE JUVENILE (NIGHT) HABITAT PREFERENCE CURVES ..... | 92 |
| FIGURE 23 | WALLEYE ADULT (DAY) HABITAT PREFERENCE CURVES ..... | 93 |
| FIGURE 24 | WALLEYE ADULT (NIGHT) HABITAT PREFERENCE CURVES ..... | 94 |
| FIGURE 25 | WALLEYE SPAWNING HABITAT PREFERENCE CURVES . | 95 |
| FIGURE 26 | RAINBOW TROUT WEIGHTED USABLE AREA VERSUS DISCHARGE FOR SEGMENT 4 ..... | 98 |
| FIGURE 27 | RAINBOW TROUT WEIGHTED USABLE AREA VERSUS DISCHARGE FOR SEGMENT 5 ..... | 99 |
| FIGURE 28 | RAINBOW TROUT WEIGHTED USABLE AREA VERSUS DISCHARGE FOR SEGMENT 6 ..... | 100 |
| FIGURE 29 | BROWN TROUT WEIGHTED USABLE AREA VERSUS DISCHARGE FOR SEGMENT 1 ..... | 101 |
| FIGURE 30 | BROWN TROUT WEIGHTED USABLE AREA VERSUS DISCHARGE FOR SEGMENT 2 ..... | 102 |
| FIGURE 31 | BROWN TROUT WEIGHTED USABLE AREA VERSUS DISCHARGE FOR SEGMENT 3 ..... | 103 |
| FIGURE 32 | BROWN TROUT WEIGHTED USABLE AREA VERSUS DISCHARGE FOR SEGMENT 4 ..... | 104 |
| FIGURE 33 | BROWN TROUT WEIGHTED USABLE AREA VERSUS DISCHARGE FOR SEGMENT 5 ..... | 105 |
| FIGURE 34 | BROWN TROUT WEIGHTED USABLE AREA VERSUS DISCHARGE FOR SEGMENT 6 ..... | 106 |

## LIST OF FIGURES (Concluded)


| | | |
|---|---|---|
| FIGURE 35 | WALLEYE WEIGHTED USABLE AREA VERSUS DISCHARGE FOR SEGMENT 1 ..... | 107 |
| FIGURE 36 | WALLEYE WEIGHTED USABLE AREA VERSUS DISCHARGE FOR SEGMENT 2 ..... | 108 |
| FIGURE 37 | WALLEYE WEIGHTED USABLE AREA VERSUS DISCHARGE FOR SEGMENT 3 ..... | 109 |
| FIGURE 38 | SAUGER WEIGHTED USABLE AREA VERSUS DISCHARGE FOR SEGMENT 1 ..... | 110 |
| FIGURE 39 | SAUGER WEIGHTED USABLE AREA VERSUS DISCHARGE FOR SEGMENT 2 ..... | 111 |
| FIGURE 40 | SAUGER WEIGHTED USABLE AREA VERSUS DISCHARGE FOR SEGMENT 3 ..... | 112 |
| FIGURE 41 | HABITAT EXCEEDENCE CURVES FOR THE COMPOSITE FISH IN SEGMENT 1 OF THE OLDMAN RIVER ..... | 122 |
| FIGURE 42 | HABITAT EXCEEDENCE CURVES FOR THE COMPOSITE FISH IN SEGMENT 3 OF THE OLDMAN RIVER ..... | 123 |
| FIGURE 43 | HABITAT EXCEEDENCE CURVES FOR THE COMPOSITE FISH IN SEGMENT 4 OF THE OLDMAN RIVER ..... | 124 |
| FIGURE 44 | HABITAT EXCEEDENCE CURVES FOR THE COMPOSITE FISH IN SEGMENT 5 OF THE OLDMAN RIVER ..... | 125 |
| FIGURE 45 | HABITAT EXCEEDENCE CURVES FOR THE COMPOSITE FISH IN SEGMENT 6 OF THE OLDMAN RIVER ..... | 126 |

## 1.0 EXECUTIVE SUMMARY

Investigations were carried out in 1988 to identify instream flow recommendations for the protection of fisheries values downstream of the Oldman River Dam. The study involved a number of components, the key elements of which were:

- Additional hydraulic measurements of the Oldman River between the damsite and LNID to enable the use of hydraulic simulation models for flows less than 20 $m^3/s$. This information completed the data sets necessary to simulate Oldman River hydraulic characteristics between the damsite and the confluence with the Little Bow River in the flow ranges of approximately 5 to 100 $m^3/s$;

- Identification of habitat preference criteria for the priority management species downstream of the damsite, specifically brown trout, rainbow trout, walleye and sauger. In the case of walleye and sauger, two life stages (spawning and fry) were not detected in the lower reaches of the Oldman and Bow rivers, or the downstream South Saskatchewan River in Alberta in 1988. Habitat preference criteria for these life stages were obtained from the Instream Flow Group of the U.S. Fish and Wildlife Service in Fort Collins, Colorado. The applicability of these walleye and sauger fry and spawning habitat preferences to the Oldman River populations could not be evaluated. The habitat preferences for the walleye and sauger juvenile and adult life stages employed in the study were developed from data collected at the Oldman River. Rainbow trout habitat preference (exclusive of the juvenile life stage) were identified from studies of the population in the Crowsnest River. Juvenile rainbow trout habitat

preference criteria had previously been developed from studies of the Oldman River downstream of the damsite (Fernet and Matkowski 1986a). Brown trout habitat preferences were developed from data collected at the Bow River in Calgary;

- Studies designed to examine the transferability of the preference criteria between rivers were generally inconclusive for a number of reasons, including an absence of walleye and sauger from the Oldman River Study Area, and low flow conditions and a low standing stock of brown trout in the Crowsnest River. The habitat preference criteria employed (with the exception of those for the spawning and fry life stages of walleye and sauger) are evaluated as being applicable to the Oldman River between the damsite and Little Bow River confluence;

- A method of identifying instream flow requirements for fish, termed the Fish Rule Curve, was identified which was acceptable to both the Fish and Wildlife Division of Alberta Forestry, Lands and Wildlife and Alberta Environment;

- Computer software was developed to conduct the analysis and interface with existing flow databases and the Instream Flow Incremental Methodology (IFIM) models;

- Streamflow requirements for the Oldman River between the damsite and the Little Bow River confluence were identified, which incorporated available water quality and temperature criteria developed by the Oldman River Dam Water Quality Working Group;

- Habitat features which were limiting productivity of the priority management species were identified. Mitigative designs were developed by the River Engineering Branch of Alberta Environment to overcome the limiting features of the downstream riverine environment within the flow ranges anticipated with reservoir operation;

- Based on the relationship between discharge and distribution of depths, velocities and substrates, the preference criteria for the priority management species, and the assumption that the necessary cover characteristics would be created for rainbow and brown trout, habitat availability under three flow regimes was estimated. The flow regimes examined were the naturalized hydrograph (i.e., estimate of natural flow without any abstractions or water management), the recorded hydrograph, and the projected flow releases with the reservoir in place and existing water demands (water balance model simulation OD05). For all river segments except for a 6 km reach immediately downstream of the damsite, reservoir releases were evaluated as providing more habitat than both the historical (i.e., recorded) and natural conditions. Physical habitat values immediately below the damsite were approximately the same for the recorded/naturalized and OD05 regimes; and,

- Flushing flow requirements for the prevention of sediment accumulation downstream of the damsite were identified.

The completion of this analysis is based on several assumptions, the most noteworthy of which is that habitat characteristics which are identified as limiting the productivity of the target species will be overcome through habitat enhancement. The simulated temperatures of reservoir releases have been noted to

have the potential for precluding successful spawning, for rainbow trout in particular. This issue must be addressed in mitigative planning. Several other considerations which are under active review, such as the potential of impacts of water management on river regime and other water quality/aquatic productivity issues, require definition to complete the assessment of anticipated downstream fisheries values and enable the formulation of the downstream mitigation strategy. However, on the basis of discharge alone, present water balance model simulations indicate major gains in microhabitat values for the fishery resource, particularly downstream of LNID when a comparison is made with recently experienced flow conditions in the river.

## 2.0 INTRODUCTION

Fisheries investigations downstream of the Oldman River Dam commenced in 1985 (Figure 1) (Fernet and Matkowski 1986a). During the late spring, summer and fall field seasons, the distribution and abundance of fishes between the damsite and the confluence of the Little Bow River were examined. In addition, the river was divided into six homogeneous segments, based on morphology and flow characteristics (Figure 2). Within each segment, a representative study reach was established where measurements of physical habitat features (depth, velocity, substrate and cover) were conducted over the range of flows which occurred. These data were used with the Physical Habitat Simulation System (PHABSIM) group of models of the Instream Flow Incremental Methodology (IFIM) (Milhous et al. 1984).

The PHABSIM group of models were developed to predict habitat availability over a wide range of flows for the species and life stages of interest. The relative value of each habitat characteristic for the species and life stage under examination must be identified to facilitate an estimation of habitat availability. To this end, the habitat preferences of the most commonly encountered life stages of the sport species within the Study Area were determined. These included the spawning, fry, juvenile and adult stages of mountain whitefish (Prosopium williamsoni), and the juvenile life stage of rainbow trout (Oncorhynchus mykiss, formerly Salmo gairdneri). With the use of this preference information, the relationship between habitat availability (Weighted Usable Area, or WUA) and streamflow in the six study reaches was determined for the range of flows measured during the 1985 field season (Fernet and Matkowski 1986a).

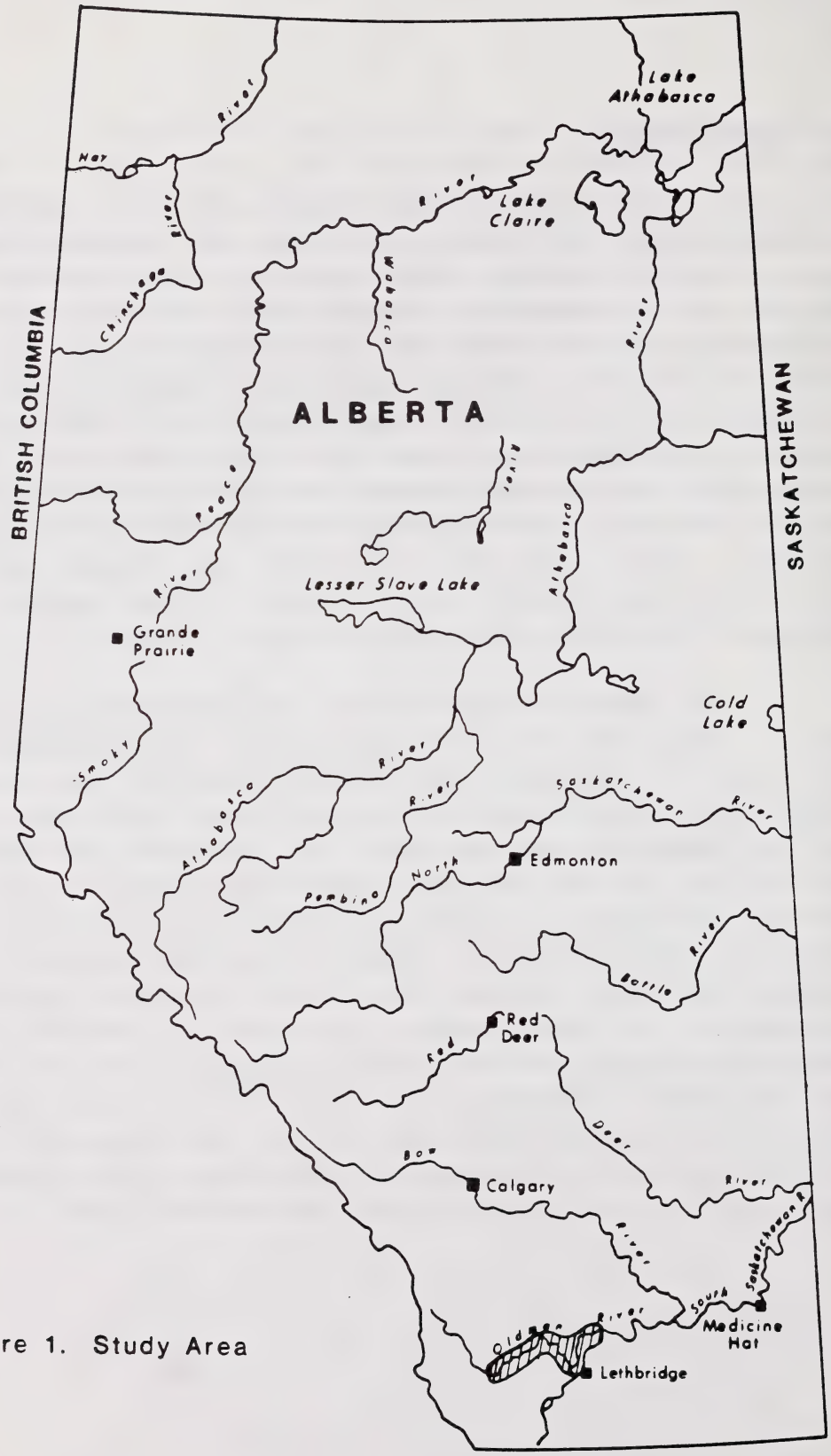



Figure 1. Study Area

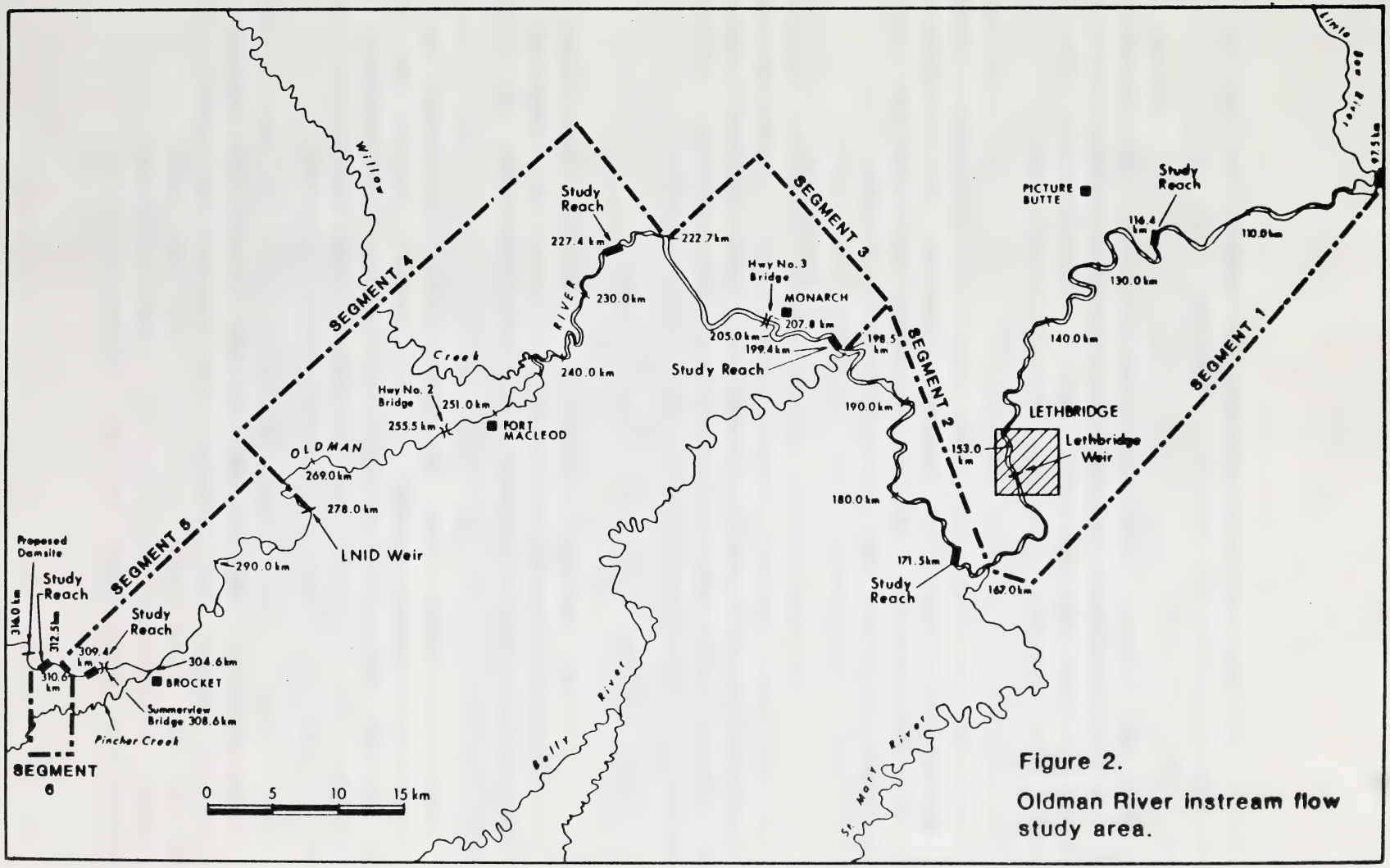



**Figure 2.**

**Oldman River instream flow study area.**

Field investigations in 1986 involved a study of the distribution, relative abundance and habitat utilization of fishes in the Study Area in the late winter and spring (Fernet and Matkowski 1986b). Hydraulic measurements were also conducted at the six IFIM sites to increase the predictive capabilities of the models (Fernet and Matkowski 1987). In addition to using the mountain whitefish and juvenile rainbow trout preference curves, the best available habitat preference information for rainbow trout spawning, fry and adults, as well as walleye (Stizostedion vitreum vitreum) and sauger (S. canadense) spawning, fry, juvenile and adult were obtained. The models were then used to estimate habitat availability (WUA) for all species and life stages.

The applicability of the preference criteria to the fauna of the Oldman River was unknown, as the habitat preference curves were not specific to the Oldman River. It was concluded that the estimates of habitat availability for the rainbow trout spawning, fry and adult life stages, as well as the walleye and sauger life stages could not be viewed with a high degree of confidence.

The fisheries information for the Oldman River downstream of the dam was critically reviewed by Alberta Environment and the Fish and Wildlife Division of Alberta Forestry, Lands and Wildlife in early 1988. At that time, the Fish and Wildlife Division identified rainbow trout and brown trout (Salmo trutta) as the priority management species in the coldwater region of the river (from the damsite downstream to the region of Fort Macleod), and walleye and sauger in the coolwater region of the Study Area (downstream of Fort Macleod) (L. Fitch, Fish and Wildlife Division, pers. comm.). Given these management priorities, the following deficiencies in the existing database in terms of developing a suitable downstream fisheries mitigation plan were identified:

1. Additional hydraulic measurements were required for study Segment 6 [damsite to 2 km upstream of Highway 785 (Summerview) Bridge] and 5 [2 km upstream of Summerview Bridge to LNID (Lethbridge Northern Irrigation District) Headworks] to facilitate modelling physical habitats for flows under 20 $m^3/s$. Flows in this range had not been measured in the upper reaches of the Study Area because they had not occurred during previous field investigations;

2. Habitat criteria for rainbow trout (exclusive of the juvenile life stage), brown trout, walleye and sauger, which were applicable to the Oldman River needed to be developed;

3. A method of identifying instream flow requirements for fishes, which was acceptable to both the Fish and Wildlife Division and Alberta Environment was required;

4. Streamflow requirements for the priority management species had to be developed;

5. An evaluation of various water management alternatives in terms of habitat losses or gains for the fishery resource was required;

6. Limiting habitat features within each of the six representative study sites needed to be identified. Habitat mitigation designs were required to overcome the limitations of the habitat, and the resultant gains in habitat availability required quantification;

7. Both preliminary (office techniques) and detailed estimates (based on field investigations) of flushing flow requirements for the maintenance of fisheries

habitat were required for inclusion in water balance modelling; and,

8. Information on a variety of water quality [i.e., thermal regime, dissolved oxygen, nutrients, gas supersaturation, turbidity, heavy metal (specifically mercury, but also including iron and manganese if anoxic reservoir releases were anticipated)] and other biotic characteristics (macrophyte and algae standing stocks, benthic invertebrate productivity) was required for the analysis. In order to facilitate such an analysis, relevant water quality standards for the priority management species were also required.

Subsequent to the review of the existing downstream fisheries information, Environmental Management Associates (EMA) was retained by Alberta Environment to address the fisheries components of the deficiencies.

## 3.0 TERMS OF REFERENCE

The tasks which were identified in the downstream fisheries investigations were subdivided into two categories, as follows:

1. Instream Flow Requirements For Fish

   a. Develop habitat criteria for rainbow trout, brown trout, walleye and sauger;

   b. Identify a suitable Instream Flow Incremental Methodology (IFIM) analysis technique which is acceptable to both Alberta Environment and Fish and Wildlife Division;

   c. Use the IFIM technique to define an appropriate flow regime downstream of the damsite for protection of fisheries resources and to evaluate the different proposed water management scenarios in terms of habitat lost or gained;

   d. Submit the results in the form of a summary report suitable for inclusion into the Fisheries Mitigation Strategy, and results of the individual components in technical appendices;

   e. Submit three bound copies of a draft report, with relevant documentation outlining the work program and results, to the Project Coordinator by January 15, 1989;

   f. Submit three bound copies of the final report to each of the Planning Division of Alberta Environment and the Fish and Wildlife Division of the Department of Forestry, Lands and Wildlife within one month of receiving editorial comments. A final camera-ready report will be

submitted to the Planning Division of Alberta Environment;

g. Present final findings at a seminar presentation as required by the Project Coordinator;

h. Submit monthly written progress statements to the Project Coordinator to accompany all invoices. Invoices submitted will contain a summary of expenditures to date, as a descending balance from approved funds; and,

i. Attend project meetings as required by the Project Coordinator.

2. Habitat Analysis

a. Identify limiting habitats based on detailed examination of six representative study sites. Design detailed habitat mitigation techniques to address these limiting habitats over the range of flows which will be experienced during operation of the reservoir;

b. Provide preliminary estimates of flushing flow requirements, based on office techniques, for immediate inclusion in water balance model runs. Carry out a field program to provide more detailed information on the magnitude, duration, frequency and timing of flushing flows required;

c. Submit the results in the form of a summary report suitable for inclusion into the Fisheries Mitigation Strategy, and results of the individual components in technical appendices;

d. Submit three bound copies of a draft report, with relevant documentation outlining the work program and results, to the Project Coordinator by January 15, 1989;

e. Submit three bound copies of the final report to each of the Planning Division of Alberta Environment and the Fish and Wildlife Division of the Department of Forestry, Lands and Wildlife within one month of receiving editorial comments. A final camera-ready report will be submitted to the Planning Division of Alberta Environment;

f. Present final findings at a seminar presentation as required by the Project Coordinator;

g. Submit monthly written progress statements to the Project Coordinator to accompany all invoices. Invoices submitted will contain a summary of expenditures to date, as a descending balance from approved funds; and,

h. Attend project meetings as required by the Project Coordinator.

## 4.0 APPROACH

The tasks identified under Instream Flow Requirements For Fish in the Terms of Reference for the study were performed by EMA. Within this component of the study, computer software was developed to analyze the IFIM results, and assist in defining the instream flow requirements for fish. The software was developed under sub-contract by Dr. Thom Hardy of Twelve Nine Inc., Logan, Utah, and was designed to interface with the PCSIM groups of models. The PHABSIM models were developed for use on a mainframe computer; Dr. Hardy had previously adapted these models for use on a microcomputer (PCSIM).

In addition to developing habitat preference criteria for use in the models, another component of the overall investigation involved an examination of the transferability of the criteria to the Oldman River. In instances where habitat preference criteria may not be developed in the watercourse under study, a variety of tests may be conducted to determine the transferability of the habitat preference criteria from the source stream where they were developed to another watercourse. In the case of the walleye and sauger habitat preference criteria, the study design involved comparing the habitat use by the life stages of these species in study reaches 1 and 2 of the Oldman River with the criteria developed elsewhere. In the case of habitat preferences developed for rainbow trout and brown trout, the transferability of these criteria was tested under a separate contract, in the Crowsnest River, with EMA acting as a sub-contractor to R. L. & L. Environmental Services Ltd. This study is documented in Appendix I of this report.

Inherent in the identification of instream flow requirements for fish is a consideration of both microhabitat and macrohabitat characteristics under an altered flow regime. Use of the PHABSIM models considers the microhabitat component of the

analysis, or the distribution of physical habitat features (in this case depth, velocity, substrate and cover) and compares the availability of these habitat features with the habitat preferences of target species. Several macrohabitat considerations are also important in the identification of streamflow requirements for fish. One such consideration includes the effects of dam construction and diversion of peak flows on channel structure, an issue which is being addressed by the Technical Services Division, River Engineering Branch of Alberta Environment.

The second major macrohabitat consideration is the potential effect of the dam on water quality and temperature. These issues, together with potential concerns regarding the related biotic considerations of effects on algae, macrophyte and benthic invertebrate standing crops are being addressed by the Oldman Dam Water Quality Working Group. The Working Group consists of representatives of the Standards and Approvals Division, Environmental Assessment Division, and Planning Division of Alberta Environment, the Fish and Wildlife Division of Alberta Forestry, Lands and Wildlife, and the Oldman Dam Project Office of Alberta Public Works. This committee is supported through the assistance of HydroQual Consulting Inc., and EMA. The information provided to date by this Working Group has been incorporated into the streamflow recommendations for fish.

Under the category of Habitat Analysis in the Terms of Reference for the study, EMA assumed the responsibility for identification of factors limiting the productivity of the various life stages of the target species. Detailed design of structures for the mitigation of limiting habitat features was conducted by the Technical Services Division, River Engineering Branch of Alberta Environment. These designs were incorporated into the existing database for the Oldman River by the Technical Services Division, and re-run through the PHABSIM models by EMA to determine the net effect on the availability of limiting habitats.

The issue of identifying flushing flow requirements for the maintenance of aquatic habitats was conducted by J.N. MacKenzie Engineering Ltd., under contract to EMA (J.N. Mackenzie Engineering Ltd. 1989).

The task of integrating the microhabitat and macrohabitat analyses was assumed by EMA, under the direction of A. Locke, Habitat Branch, Fish and Wildlife Division, who was designated the scientific officer for the downstream fisheries instream flow needs study.

# 5.0 METHODS

## 5.1 COLLECTION OF LOW FLOW HYDRAULIC DATA

The majority of the IFIM hydraulic data for the Oldman River downstream of the proposed damsite was collected during previous study programs (Fernet and Matkowski 1986a, 1987). Hydraulic measurements for the low stage target flow (7 $m^3/s$) for Segments 5 and 6 were conducted in the early spring of 1988. Measurements were performed at transect locations which had originally been established in 1985 (Figure 2), to provide data complimentary to those collected in 1985 and 1986. In one instance where an access bridge was constructed below the damsite, one transect (study reach 6, upper transect) was eliminated from the study as this transect had been altered during bridge construction (Fernet and Matkowski 1987).

On 21 and 22 March, 1988, a two-man crew visited study reaches 5 and 6 to complete the preliminary survey work required prior to conducting hydraulic measurements. Survey equipment used during these field studies included an automatic level (Nikon AE-5), a metric survey rod, a magnetic pin locator (Schonstedt GA-52B), and an electronic distance meter/optical theodolite combination (Nikon NTD-4).

Transect locations were originally established in 1985 and marked with permanent headpins (Fernet and Matkowski 1986a). Due to disturbances such as ice scour, some headpins were adjusted or replaced in 1986 (Fernet and Matkowski 1987). The survey work in 1988 included relocating these headpins. All headpins were located and geodetic pin elevations re-determined except for the left downstream bank headpin on transect 2, reach 5, which was disturbed by the landowner. This pin was re-established in its original position by triangulation techniques using the electronic distance meter/theodolite. The distance and trigonometric

information for this headpin (relative to other undisturbed headpins) was provided by the original survey results (McElhanney Group Ltd. 1985). Differential levelling was performed as described in Bovee and Milhous (1978) to determine elevations of the headpins relative to a benchmark established in 1985. A level loop closure (accuracy $\pm$ 0.003 m) was performed on all headpins in each study reach to ensure adequate precision of measured headpin elevations (Bovee and Milhous 1978).

Detailed hydraulic measurements (depth and velocity distributions) were conducted in reach 5 on 23 March and in reach 6 on 24 March, 1988. Water surface elevations at each transect were determined relative to the transect headpins and the wetted perimeter between transects was measured.

Techniques used to collect hydraulic data followed the specifications for use of the IFG4 hydraulic model (Bovee 1982). Methods and equipment used for measurement of stationing, depths and velocities were identical to those used in 1985 (Fernet and Matkowski 1986a).

The discharges at which measurements were conducted in 1988 were: 7.86 $m^3/s$ for Segment 5 and 7.16 $m^3/s$ for Segment 6. These data were used to facilitate habitat simulation in the low flow range.

## 5.2 DEVELOPMENT OF HABITAT PREFERENCE INFORMATION

Habitat preference criteria for the life stages of the target species were developed according to the guidelines established in the Fish and Wildlife Division manual for the Province of Alberta (Fernet and Walder 1986). Within the manual, source streams for the development of habitat preference criteria are identified for various fish species within the nine river basins in the province.

Habitat preferences for brown trout were investigated in the Bow River. The Bow, which is a component of the South Saskatchewan River drainage, provides a diversity of available habitat types and a good standing stock of brown trout. The Crowsnest River downstream of Lundbreck Falls was the source stream for developing rainbow trout habitat preferences. It was anticipated that this watercourse would provide a good diversity of available habitat types as well as a high standing crop of rainbow trout. In addition, as the rainbow trout population downstream of Lundbreck Falls is the same population which inhabits the upper reaches of the Oldman River, the habitat preference curves developed for this population would apply to the individuals who become established downstream of the dam.

The source stream used for the development of walleye and sauger habitat preferences was the Oldman River at Grand Forks. The Oldman River had been recommended for development of habitat preferences for walleye and sauger (Fernet and Walder 1986), and use of the Oldman River eliminated the concern regarding transferability of the criteria. The Oldman River also provided a wide variety of habitat types, and it was determined from spring electrofishing for spawning walleye and sauger that population levels were highest in the region of the confluence with the Bow River. In addition, if low numbers of a particular life stage were encountered in the identified study site, the proximity of the lower reaches of the Bow River, as well as the South Saskatchewan River downstream of the confluence of the Bow and Oldman rivers at Grand Forks provided further sampling locations if required.

### 5.2.1 Collection of Habitat Availability Hydraulic Data

The first procedure followed in establishing a study reach was to identify a site which provided a wide array of available habitat types, and good populations of all life history stages of interest for the target fish species. Additional study

site requirements were easy and reliable access, and river morphology characteristics which did not create difficulties for the computer models.

Study reaches were defined by major hydraulic controls at the top and bottom ends of the site, through which transects were placed. Transects were marked with permanent headpins placed the endpoints of each transect. Transects were placed through all apparent controls in the study reach as well as through all habitat types present (e.g., pool, riffle, run), and transition zones between habitat types. Crowsnest River thalweg elevations were determined every 7 m along the length of the study reach at the time of transect placement to ensure that all minor controls in the reaches were defined by transects. At the study sites on the Oldman and Bow rivers, conducting a thalweg survey was judged to be impractical due to the size of these watercourses.

The relative elevations of the permanent headpins marking transects were determined for all study reaches by surveying a level loop closure on the headpins in relation to a permanent benchmark, using the technique of differential levelling as described in Bovee and Milhous (1978). The equipment utilized for this process included a Nikon AE-5 automatic level, or comparable equipment provided by the Fish and Wildlife Division, and a 7-m telescoping survey rod with rod level. In addition, the horizontal distance between each successive headpin was determined in order to allow for relocation of any headpin that may be disturbed.

A schematic diagram was prepared for each study reach illustrating general river morphology, placements of transects, headpins and benchmark, and any features or landmarks significant to their location.

The techniques employed during the collection of hydraulic and habitat information at study transects and the data

recorded followed the specifications for use of the IFG-4 hydraulic model (Bovee 1982). The data collected at each station (vertical) along each transect included water depth (streambed elevation at dry stations), mean column velocity, nose velocity, as well as substrate and cover information. Stationing across each transect was established with the use of a tagline consisting of a 100 or 250 m length of 3.2-mm diameter aircraft cable marked at 1 m intervals. The tagline was anchored on each bank over the respective headpins for the transect and suspended above the water using a hand-operated winch (come-a-long). Identical stationing was employed throughout the study. In addition, water surface elevations at each transect were determined in relation to transect headpin elevations, and the shoreline distances between transects were measured. All information was recorded on data sheets specifically designed for IFIM information.

Measurements at study reaches were conducted according to the standards established by the Instream Flow Group of the U.S. Fish and Wildlife Service (Trihey and Wegner 1981). Depth and velocity measurements on transects which could be waded were conducted with the use of top-setting wading rods and Price 622 AA or Marsh McBirney M201 water velocity meters. All velocity meters employed were calibrated by the National Calibration Service of Environment Canada. On transects where depths were too great to enable wading, depth and velocity determinations were conducted from a 3-m inflatable boat (Zodiac) attached to a steel tagline. Depth measurements were made with a Model 3300 Type B-56 winch equipped with a computing-type counter and a 22.7 kg weight. Velocity measurements were made with a Price 622 AA current meter suspended on a M-2 hanger incorporated in the suspension system.

Water Survey of Canada procedures were employed in conducting mean column velocity measurements (Terzi 1981), including determinations of velocity at 6/10 water depth where water depth was less than 0.75 m and determinations at 2/10 and

8/10 water depth where depth was equal to or exceeded 0.75 m. All measurements were recorded in metric units. Discharge calculations were conducted on an IBM model 50 computer from data recorded at transects identified in the field at the time of measurement as being best-suited for this purpose.

Nose velocities were measured at 0.1 m above the streambed at stations where water velocities were determined using the top-setting wading rod. At stations where water velocities were conducted using the depth-computing winch and weight apparatus, nose velocities were measured at 0.2 m above the streambed, as this was the minimal distance from the bottom at which the equipment would function properly. Nose velocity information is stored in data files, as mean column velocities were used in the development of preference information, and in running the hydraulic models.

A metric staff gauge was placed in each study reach during the periods when hydraulic measurements were being conducted. The staff gauge reading was recorded at the start and finish of the measurements at each transect in order to monitor any changes in river stage that might occur.

Substrate (percent composition) and cover (according to life stage) data were recorded for all stations during the low stage measurement at each of the study reaches. The criteria employed in these determinations are presented in Tables 1 and 2. Weighted average index values were developed from the substrate data for use with the PHABSIM models, as described by Fernet and Walder (1986).

## TABLE 1

## SUBSTRATE DEFINITIONS AND SIZE-RANGE CATEGORIES

| | Size Range | |
|---|---|---|
| Class Name | mm | Inches |
| Detritus | | |
| Clay\Silt | <0.062 | <0.0024 |
| Sand | 0.062-2.0 | 0.0024.0.08 |
| Small Gravel | 2-8 | 0.08-0.03 |
| Medium Gravel | 8-32 | 0.03-1.3 |
| Large Gravel | 32-64 | 1.3-2.5 |
| Small cobble | 64-128 | 2.5-5 |
| Large Cobble | 128-256 | 5-10 |
| Small Boulder | 256-762 | 10-30 |
| Large Boulder | >762 | >30 |
| Bedrock | | |

**TABLE 2**

**COVER-TYPE CODINGS, DEFINITIONS AND FUNCTIONS**

| Code | Type | Function | Examples |
|---|---|---|---|
| 1 | No cover | No cover | No cover, deep pool |
| 2 | Instream object | Velocity shelter | Boulders, partially buried logs, bedrock ledges |
| 22 | Instream object, edge effect | | |
| 3 | Instream overhead | Direct visual isolation | Undercut bank, log jams, surface turbulence, deep pools |
| 33 | Instream overhead, edge effect | | |
| 4 | Offstream overhead | Indirect visual isolation | Overhanding canopy |
| 44 | Offstream overhead, edge effect | | |
| 5 | Combination object and overhead | Combination velocity shelter and visual isolation | Root wads, brush piles, emergent vegetation, compact log jams, any superimposed object with overhead cover |
| 55 | Combination object and overhead, edge effect | | |

[a] edge effect = interface between two distinct habitat types

A photographic record was taken at each study reach during each stage measurement to illustrate the appearance, morphology and dynamics of the reach during the different flow conditions.

IBM PC-compatible computer systems were used to analyze the data collected. Calibrated single-flow data decks were utilized to determine the habitat availability (depth, velocity, substrate and cover) within each study reach for each discharge at which habitat utilization information was collected.

For the rainbow trout spawning life stage in the Crowsnest River, the required number of habitat use observations could not be found in the study reach. In this case, habitat availability was determined by a random sampling technique. With this method, availability was determined with a number of random habitat measurements collected in the area around each habitat utilization observation (Bovee 1986).

#### 5.2.1.1 Bow River

On 8 April, 1988, an IFIM study site was established on the Bow River, in the Inglewood district of the City of Calgary (Figure 3). This site was established for the collection of habitat utilization and availability data for the spawning, fry, juvenile and adult life stages of brown trout. Site selection was primarily based on the historical significance of this location as a brown trout spawning area. Studies conducted by the Fish and Wildlife Division identified the Inglewood site as a major spawning area for brown trout on the mainstem Bow River (Sosiak 1983, Wiebe and Konynenbelt 1980). This spawning area comprised a portion of the actual IFIM study reach. The complete study reach encompassed a region of the Bow River which contained a wide range of available habitat types.

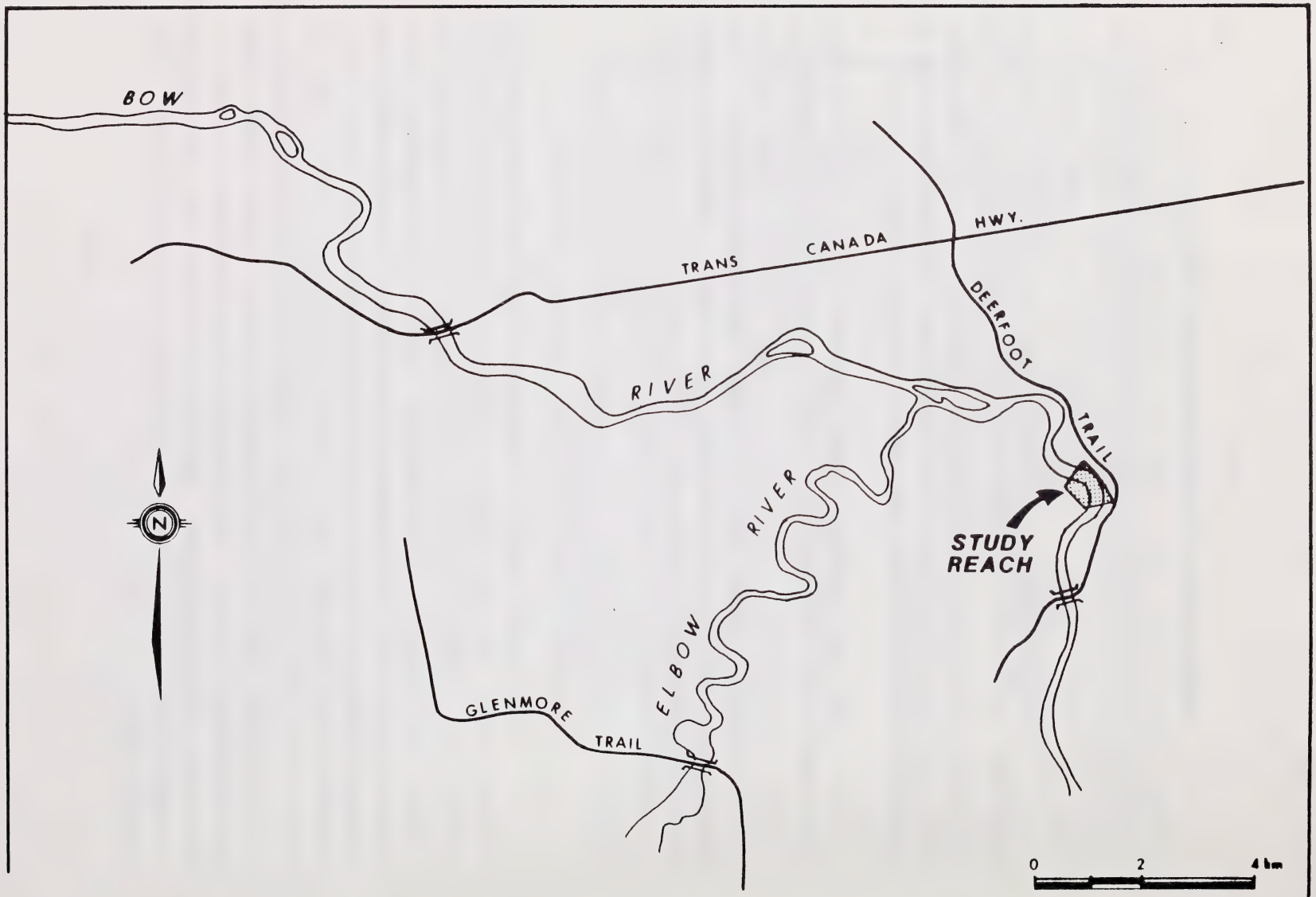



Figure 3. Location of Bow River study reach, 1988.

Transects were established by EMA staff in consultation with Fish and Wildlife Division personnel. Permanent headpins were placed at the endpoints of each transect and a level loop closure was conducted to determine the elevations of the headpins relative to a permanent benchmark. Alberta Survey Control Benchmark #183454 was located within the study reach and was utilized for this purpose. This permitted the calculation of the geodetic elevation for all transect headpins. Horizontal distances between successive headpins were measured and a schematic diagram of the study reach showing transect and headpin locations was produced.

On 14 to 15 April, a set of measurements was conducted involving water depth, mean column velocity, nose velocity, substrate and cover information at all stations established on each transect. The river discharge at this time was 62.6 $m^3/s$. On transects with high embankments, workpins were established below the embankments and between the headpin and the water's edge. All headpin-to-workpin distances were recorded. Water surface elevations in relation to transect headpins were determined and the shoreline distance between each successive transect was measured. A photographic record of the study reach was taken at this time.

On 2 June, a discharge was determined ($Q = 88.9\ m^3/s$) and water surface elevations were measured at all transects on the study reach. A photographic record of the study reach was also taken.

During collection of habitat utilization data later in the summer, it was determined that some life stages of brown trout were utilizing submergent vegetation as both instream and overhead cover. During the period when cover analysis had been initially completed, aquatic vegetation was not present. On 15 to 16 November, cover measurements were repeated for transects where weedbeds had developed since the cover data was originally collected.

#### 5.2.1.2 Oldman River

On 16 May, 1988, an IFIM study site was established on the lower Oldman River, immediately upstream of Grand Forks (Figure 4), for the collection of habitat utilization and availability information for fry, juvenile and adult life stages of walleye and sauger. This site was identified from the results of electrofishing efforts during the spring walleye/sauger spawning study as providing the best access and highest density of walleye and sauger juvenile and adults. Water depths and velocities throughout the study site were sufficiently varied to ensure the availability of a wide variety of habitat types even under anticipated low flow conditions.

On 16 May, transects were established in the study reach by EMA staff with the placement of permanent headpins. A level loop closure was conducted to determine the elevations of the headpins relative to a permanent benchmark which was also established by EMA. On 17 May, a set of measurements was conducted with water depth, mean column velocity, nose velocity, substrate and cover information being recorded at stations established on each transect. In addition, water surface elevations and wetted perimeter distances were determined. A schematic diagram of the study reach illustrating transect locations was prepared, and photographs were taken to record the appearance of the study site under prevailing flow conditions. This data set provided the high river stage ($Q = 77.9\ m^3/s$) measurement.

Two other sets of flow measurements were conducted at this study site, one on 23 June (medium flow conditions, $Q = 30.0\ m^3/s$) and one on 21 July (low range flow conditions, $Q = 12.5\ m^3/s$). The procedure followed was identical to that documented for the first set of measurements with the exception that substrate and cover determinations did not have to be repeated.

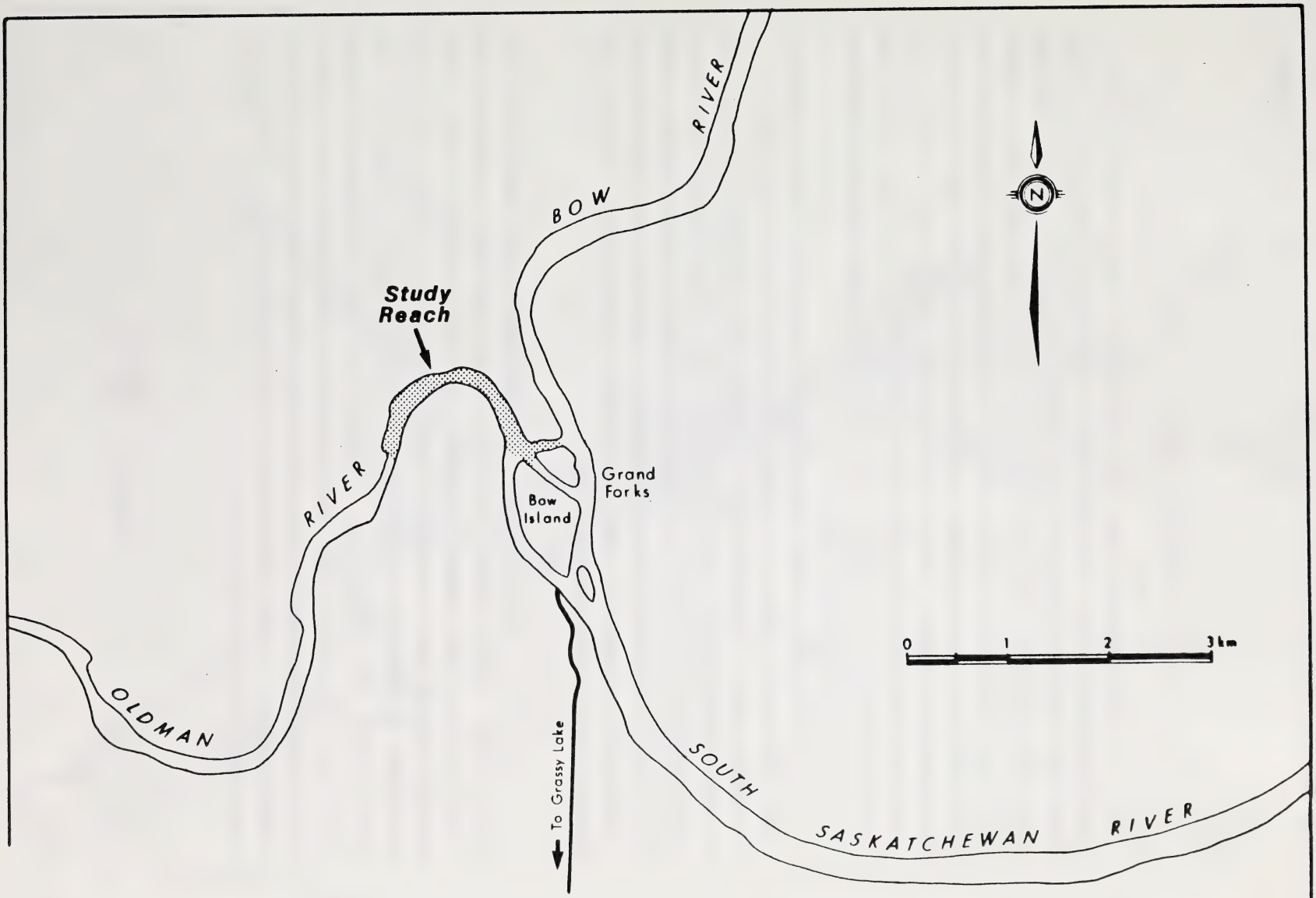



Figure 4. Location of Oldman River (Grand Forks) study reach, 1988.

5.2.1.3 Crowsnest River

On 25 March, 1988, an IFIM study site was established on the Crowsnest River, near the Town of Lundbreck (Figure 5). This site was identified for the collection of habitat utilization and availability data for the fry and adult life stages of rainbow trout in consultation with R.L. & L. Environmental Services Ltd. personnel who had previously conducted population investigations on the Crowsnest River. This site was selected because it had a wide array of available habitat types under a typical flow regime, and a high density of rainbow trout based on available information (O'Neil and Hildebrand 1986).

Transects were established by EMA staff in consultation with Fish and Wildlife Division personnel after completion of a thalweg survey. Transects were marked with permanent headpins and a level loop closure was conducted to determine the elevations of the headpins relative to a permanent benchmark established by EMA. Horizontal distances between successive headpins were measured and a schematic diagram of the study reach illustrating transect and headpin locations was completed.

On 17 April, a set of measurements was conducted with water depth, mean column velocity, nose velocity, substrate and cover information being recorded at the stations which were established on each transect. Water surface elevations and wetted perimeter distances were determined, and a schematic diagram of the study site was prepared. Another set of measurements were performed on 25 May. The river discharge rate during the 17 April and 25 May measurements were calculated as 4.8 $m^3/s$ and 10.8 $m^3/s$, respectively. During both sets of flow measurements, photographs were taken of the study reach.

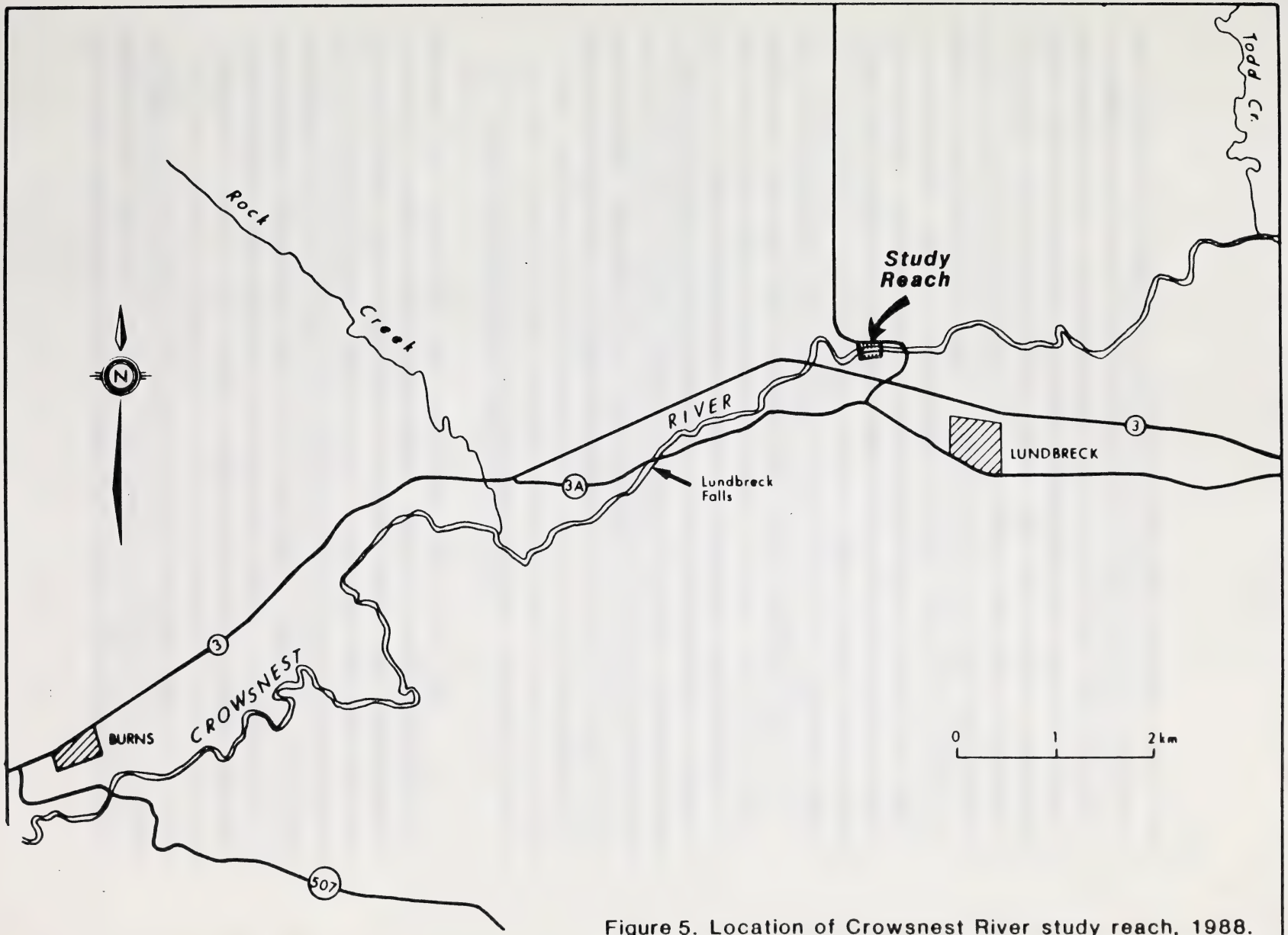



Figure 5. Location of Crowsnest River study reach, 1988.

For the spawning life stage of rainbow trout, it was anticipated that only a small portion of the required number of observations were likely to be obtained from within the IFIM study reach. Since the majority of spawning observations were noted outside of this site, the technique of random measurements was utilized to provide a quantification of habitat availability during the rainbow trout spawning period. This was accomplished by taking a number of random habitat measurements in the vicinity of an observed rainbow trout spawning event (Bovee 1986). Subsequent to locating an active redd or an area with a number of redds, transects across the river channel were established at approximately 25 m intervals upstream and downstream of the identified spawning site. In addition, one transect was placed across the site itself. Habitat measurements were then conducted at three points (one-quarter, one-half, three-quarters of transect length) along each transect. The number of transects established at each site was equal to that required to provide twice as many habitat availability measurements as spawning observations collected. A total of 336 random habitat availability data points was collected.

### 5.2.2 Collection of Habitat Utilization Data

The preferred technique for collection of habitat utilization data for the determination of habitat preference information is direct observation of individual fish in their natural habitat (Fernet and Walder 1986). During this study, the basic strategy utilized was underwater observation. This method is the most valuable of all data collection techniques and procures the most highly rated information in terms of the quality of habitat utilization point observations.

The least disruptive method of underwater observation is snorkelling (Fernet and Walder 1986). Habitat utilization observations were obtained by floating the watercourse with a dry

suit, mask and snorkel. At fish observation locations, the exact instream position of each fish was marked with a numbered marker. The data measurements collected for each observed fish were cross-referenced by the diver to the number on the appropriate marker using an underwater writing slate. Observed fish were identified to species and life-history stage (fry, juvenile or adult) by estimation of fork length. Fork lengths of observed fish were estimated by comparison to a short length of lathe marked off in decimeters and carried by the diver. Other information recorded included the number of fish observed at each location, the activity of the fish at the time of observation (e.g., feeding, holding) and an estimation of fish depth or the position of the fish in the water column (recorded as distance from the substrate).

The recommended sampling strategy for obtaining fish observations by snorkelling is to work in an upstream direction (Fernet and Walder 1986). Nearly all fish species orient themselves into the current; with the use of this technique the diver approaches the fish from behind. In addition, a constant rate of movement could be maintained while working upstream, which provides a more uniform sampling effort in each type of available habitat, regardless of water velocity, thereby reducing sampling bias.

Upstream movement during snorkelling observations was facilitated through the use of a drop line and mountaineering equipment to support the diver. A length of 3.2-mm diameter aircraft cable was deployed across the stream perpendicular to the current. This length of cable was anchored on each side of the stream and tightened with the use of a hand winch in order to suspend it above the water. A drop line consisting of a length of 12.7-mm diameter polypropylene rope was attached to the cable and dropped to the water. The rope then floated on the surface along the section of the stream to be examined by the diver. The position of the drop line in the active stream channel was adjusted

by moving the point where the line was attached to the anchor cable. In this manner the entire width of the stream could be sampled. The diver was attached to the drop line by a mountaineering harness equipped with a quick-release caribiner. The diver worked upstream along the drop line. This apparatus allowed the observer to hold position in the stream, reducing diver fatigue, and permitted free hands to record data and place observation markers.

In some instances water velocities were too fast to allow the diver to move upstream along the drop line, or to safely hold in position. In these areas, observations were obtained by floating free with the current. In such cases the diver was moving too fast to make lengthy observations and information on fish activity could not always be determined. The quality of these observations in relation to those made using the drop line was tested by employing both floating techniques in the same stretch of stream. As a first step in this process, the position of an observed fish was marked while floating downstream with the current. It was found in a high number of cases that the fish could be located in the same position by a diver moving upstream through the same area along the drop line.

The underwater observation technique was directly affected by water clarity and had to be abandoned at some sites or during certain sampling periods when turbidity levels were too high. In these cases observations were collected using electrofishing techniques. At locations where fish were observed while electrofishing, the instream position of each fish was marked as closely as possible with a numbered marker. Data recorded and cross-referenced to the number of the marker included species, life stage, estimated fork length, and number of fish. Fish depth and activity could not be determined by this technique. Boat electrofishing equipment consisted of a 5000 watt boat-mounted electrofisher (Smith-Root Model 5.0 GPP), operated from a 5.6-m

fibreglass river boat equipped with a Smith-Root electrofishing workstation and propelled by a 80 hp jet motor. Electrofishing effort was recorded in seconds.

The young-of-the-year (fry) life stage for brown and rainbow trout were found to be utilizing the shallow, low velocity littoral areas of the study sites which provided good visual cover. These areas were too shallow to be sampled effectively by the direct observation technique as the diver was unable to maneuver, particularly without causing a significant disturbance to the fish. Observations for trout fry were conducted using a backpack electrofisher (Smith-Root Model 15A). The data recorded was the same as that for boat electrofishing observations.

Observations for spawning rainbow and brown trout were obtained using the surface observation technique (Bovee 1986), as this method was very effective for these types of observations and caused minimal disturbance to the fish.

Subsequent to completing fish observations in a section of the stream, habitat measurements were conducted at each of the deployed observation markers. For brown trout and rainbow trout spawning observations, habitat measurements were taken immediately beside the redd in the undisturbed area next to the excavation. At the location of each marker, measurements were recorded for water depth, mean column velocity, velocity at fish depth (nose velocity), substrate composition, and type and distance from cover. Methods used to conduct these measurements were the same as those presented in Section 5.2.1. For observations made while boat electrofishing, where actual fish depth was not determined, nose velocities were measured at a standard distance from the bottom. This distance was either 0.1 m or 0.2 m depending on the apparatus required to complete the measurement (Section 5.2.1). All information was recorded on fish habitat point observation forms specifically developed for this purpose.

A measurement of river discharge rate at each study site was completed at the start of each observation period to define the flow rate at which the habitat utilization observations were made. A staff gauge was installed in the study reach at the start of each study period and the staff gauge reading at the time of discharge measurement was recorded. The staff gauge was monitored throughout the period in which observations were conducted; if a significant (>10%) change in the discharge was indicated, the discharge measurement was repeated.

The size ranges for the life stages of the target species under investigation in this study are summarized on Table 3.

#### 5.2.2.1 Bow River

Point observations for developing habitat utilization data for fry, juvenile and adult life stages of brown trout were conducted in the Bow River IFIM study reach during the following periods: 15 to 16 August, 19 August, 1 to 2 September, 6 to 9 September, 20 to 22 September, and 26 to 28 September. Whenever possible, data were collected using the direct observation technique. However, due to construction/repair work being conducted at an upstream damsite, high flow rates and associated high turbidity conditions were experienced during portions of the study period. When turbidity precluded observation, data were obtained using boat and backpack electrofishing methods. Boat electrofishing was also utilized in habitat types where diver observations were ineffective. These sites included the extremely deep areas of the study reach and low velocity areas where good cover was present. One of the major limitations with the direct observation technique is that the diver's field of vision must exceed the maximum depth of the stream (Bovee 1986).

## TABLE 3

## FORK LENGTH CATEGORIZATIONS OF LIFE STAGES EMPLOYED IN THIS STUDY

| Species | Adult (mm) | Juvenile (mm) |
|---|---|---|
| Rainbow Trout (Oldman River) | $\geq$350 | <350 |
| Rainbow Trout (Crowsnest River) | $\geq$250 | <250 |
| Brown Trout (Bow River) | $\geq$300 | <300 |
| Walleye | $\geq$400 | <400 |
| Sauger | $\geq$350 | <350 |

The total number of observation data points recorded from the Bow River for brown trout was as follows: 156 fry; 158 juvenile; 105 adults. All 156 brown trout fry observations were collected using backpack electrofishing techniques. For adults, 87 data points were obtained by electrofishing, while 18 were obtained by direct observation. For juveniles, 105 data points were collected by electrofishing and 53 by direct observation. Fork length ranges used to distinguish adult and juvenile fish were obtained from previous studies of the Bow River brown trout population (Sosiak 1983).

Investigations of habitat utilization by spawning brown trout were initiated on 18 October. The presence of brown trout redds during the examination of the study reach on 18 October confirmed that spawning activity had been initiated. The number of redds present, in comparison to the numbers found during surveys in previous years indicated that peak spawning activities had not occurred, and the study was temporarily postponed. All observations were conducted during the period 24 to 25 October.

On 18 October, a staff gauge was installed within the IFIM study reach and the daily river discharge rate was monitored using both staff gauge readings and flow information available from Alberta Environment's flood forecasting service. Also at this time, existing brown trout redds were marked using weights with attached streamers of orange flagging tape. A felt marker was used to record the redd number and the date on the flagging tape.

The rate of river discharge at the study site was measured on 24 October. Redds at which the markers had been disturbed or in which the streamers had been completely or partially buried were considered to be redds that were actively worked on by trout since the markers were placed on 18 October. In addition, all unmarked redds located on 24 October were known to have been constructed during the period between 18 October and 24

October. Monitoring of the river stage during this same period determined that no significant (>10%) change in flow rate had occurred at any time since the establishment of the staff gauge on 18 October.

Habitat measurements were conducted on 24 October at all redds where brown trout spawning activity was observed, and at redds known to have been constructed during the period between 18 and 24 October. All redds at which habitat data were collected were marked at the time of measurement. On 25 October, measurements were made at all remaining unmarked redds. Habitat utilization data were obtained from a total of 162 brown trout redds from the Bow River study reach.

#### 5.2.2.2 Oldman River

Walleye-Sauger Spawning Investigations

In the spring of 1988, the Fish and Wildlife Division office in Lethbridge initiated an April/May angling closure at the Grand Forks area of the South Saskatchewan River to allow for undisturbed spawning of walleye and sauger. Previous information from fisheries surveys conducted by Fish and Wildlife Division personnel suggested this area may be significant to spawning populations of walleye and sauger. Although specific spawning sites had not been identified, significant spawning congregations had been found in the vicinity of the Grand Forks (Glenn Clements, Fish and Wildlife Division, pers. comm.).

During the period 18 to 22 April, a two-man crew from EMA conducted electrofishing investigations on the Oldman, Bow and South Saskatchewan rivers in the Grand Forks region (Figure 6), to locate spawning concentrations of walleye and sauger and to identify spawning sites. Walleye and sauger are known to spawn at

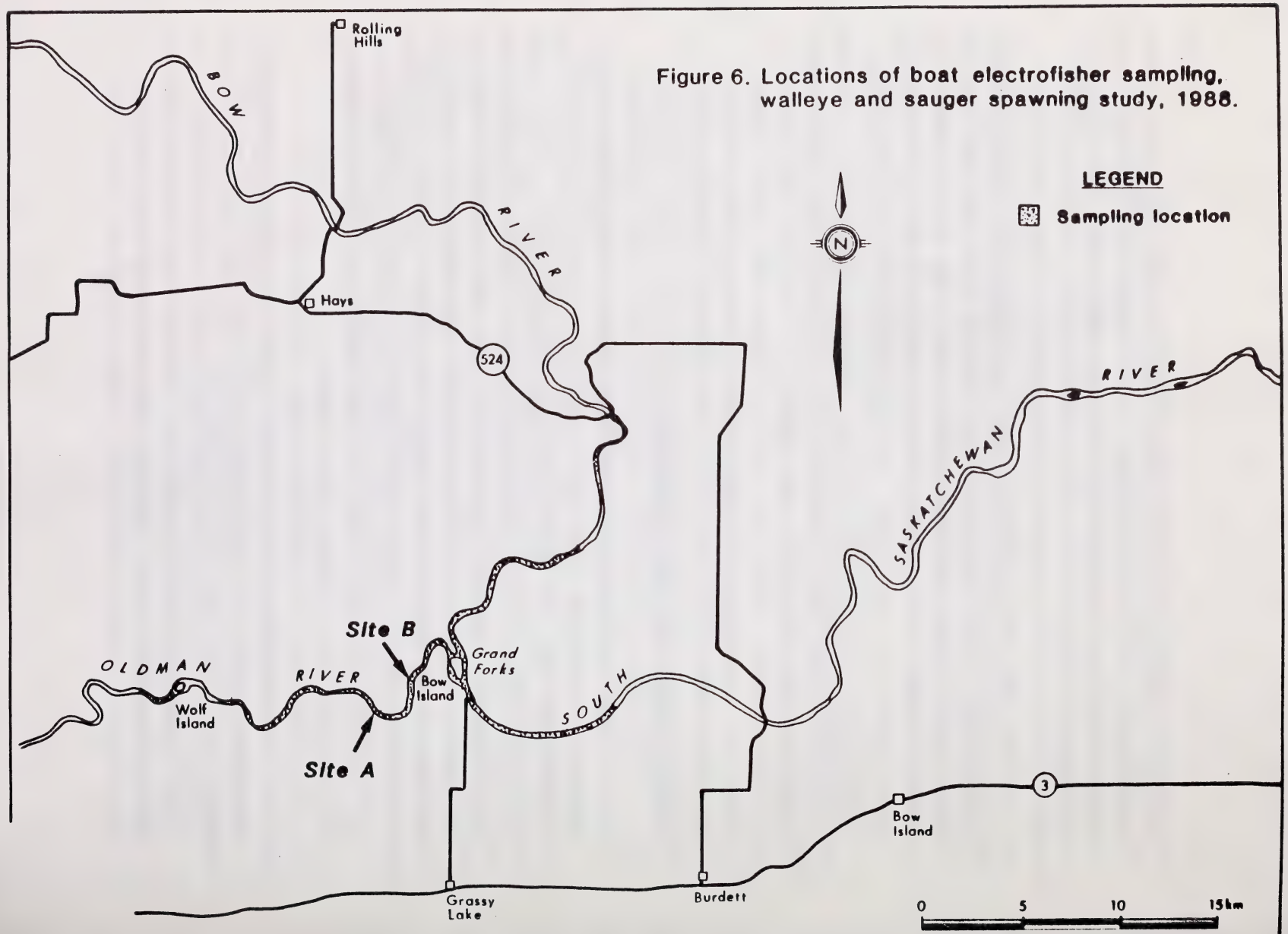



Figure 6. Locations of boat electrofisher sampling, walleye and sauger spawning study, 1988.

night (Colby et al. 1979, Scott and Crossman 1973). Electrofishing operations were carried out during daylight, twilight and night light conditions in an attempt to locate concentrations of spawning adults, both in holding areas and at actual spawning sites.

At the onset of the study period water temperatures ranged from a daytime low of 11.0°C to a high of 14.0°C, which is higher than the temperature range at which walleye and sauger spawning has been documented (McMahon et al. 1984, Scott and Crossman 1973). Walleye and sauger have been reported to initiate spawning at 3.9 to 6.1°C (Paetz and Nelson 1970, Scott and Crossman 1973), with most spawning activity occurring over the temperature range of 5.6 to 11.1°C. Sauger often spawn immediately after walleye (Scott and Crossman 1973).

During the initial study period, a total of 14,919s of electrofishing effort was recorded in the Grand Forks region (Figure 6). A total of 46 adult walleye was captured, consisting of 29 ripe males, 14 gravid (but green) females and 3 spawned-out fish, 2 of which were females. In addition, a total of 11 adult sauger was captured, consisting of 10 gravid (but green) females and 1 ripe male. The capture rates for adult individuals was low [catch-per-unit-effort (CPUE): walleye 0.31 fish/100 s; sauger 0.07 fish/100 s], and no concentrations of walleye or sauger occurred anywhere in the Study Area.

Low CPUE numbers in combination with the fact that the majority of females were still green led to the conclusion that spawning activity was just commencing despite the rapid early spring increase in water temperatures. A small number of female walleye and sauger were sacrificed for internal examination to confirm that fish examined externally were being correctly identified as gravid or spent. For ripe fish (fish which extruded either eggs or sperm with slight pressure applied to the ventral surface), no such dissection was necessary.

One site on the Oldman River (Site A, Figure 6) was identified as the most probable spawning area. Although flow rates on the Oldman River fluctuated considerably, this site was, under most flow regimes experienced during the study a natural barrier to fish passage. Blockages which impede upstream movements by spawning fish are often associated with walleye spawning areas (Scott and Crossman 1973). This site possessed a wide range of available habitat types in terms of water velocity, water depth and substrate composition, as well as being a location that was relatively free of aquatic macrophytes. Aquatic macrophytes were extremely prolific over the remainder of the Study Area. During a meeting in Taber, Alberta, Fish and Wildlife personnel confirmed Site A was a suspected walleye/sauger spawning area, and also identified other locations on the Oldman River as suspected spawning sites (Glenn Clements, pers. comm.). Electrofishing investigations were conducted from Site A downstream to the Grand Forks on two separate occasions, one of which was during the day and the other after dark. No concentrations of walleye or sauger were encountered at this site or at any of the potential downstream holding areas.

It has been reported that walleye spawning activity occurs at the surface (Colby et al. 1979, Scott and Crossman 1973), with courtship behaviour and the actual spawning act creating observable surface disturbance. Observations at Site A were conducted at night in an attempt to establish direct visual evidence of spawning activity. The site was approached by road access in order to minimize potential disturbance to the fish. Two observers equipped with flashlights surveyed this region from shore and carefully waded through the area. Numerous observations of white sucker (Catostomus commersoni) spawning were made, which confirmed results of earlier electrofishing efforts. Large concentrations of white suckers had been encountered at Site A and in downstream holding areas. However, no walleye or sauger were observed in the area.

The largest concentration of adults of the target species found during the initial study period consisted of 5 ripe male walleye captured at Site B (Figure 6) on the Oldman River. Due to the low capture rate for walleye and sauger, the lack of any significant concentrations of adult fish, and the fact that the majority of females had not yet reached spawning condition, the study was postponed for a period of one week.

A two-man crew returned to the Grand Forks area for the period 29 April to 8 May to continue the investigation. In addition to the equipment detailed previously, a 3.8-m inflatable boat (Zodiac) powered by a 35 hp outboard jet was used to gain access to upstream sections of the Bow and Oldman rivers where launch sites for the large river boat were not available. The previously described boat electrofishing unit has been specifically modified for operation from the Zodiac.

Daytime water temperatures between 29 April and 8 May ranged from a low of 12.0°C to a high of 15.5°C. The Study Area was extended to include the Wolf Island vicinity of the Oldman River and an area of the Bow River downstream of the Highway 524 crossing (Figure 6). During this time period, a total of 49,549 s of electrofishing effort was recorded.

The CPUE for adult walleye (0.20 fish/100 s) was lower than it was during the previous portion of the spring spawning study. No significant concentration of adults was located. A total of 101 adult walleye was captured including 3 green females, 90 ripe adults (3 of which were female) and 8 spawned-out fish (6 of which were female).

The CPUE for adult sauger (0.09 fish/100 s) was notably higher than during the previous investigation. However, this was more likely due to increased electrofishing effort in the section of the Bow River near the Grand Forks and in the South Saskatchewan

River, where sauger numbers were found to be higher, rather than due to any substantial migration of sauger into the Study Area. A total of 43 adult sauger was captured including 14 green fish, 16 ripe adults (6 of which were female) and 13 spawned-out fish (11 of which were female).

The study results indicate that the majority of spawning activity for the walleye and sauger captured in the Study Area occurred during the second portion of the spring spawning study. Spawned-out females of both species were encountered in increasing numbers during the 29 April to 8 May time period.

During extensive electrofishing efforts on the Oldman River, Bow River and South Saskatchewan River, no significant concentrations of adult walleye or sauger were located, although a small group of ripe male walleye was again encountered at Site B (Figure 6). Male walleye and sauger are known to precede females to the spawning grounds and to remain there after the females have left (Colby et al. 1979, Scott and Crossman 1973). On the prospect that Site B was an active spawning area, kick samples were collected at this site in order to determine if walleye or sauger eggs were present. In addition, kick sampling was conducted at three other sites, where small congregations of ripe male and female walleye had been captured while electrofishing, a criterion recognized as possible evidence of spawning activity (Bovee 1986). No such sites were located for sauger. Kick samplers consisted of 30.5-cm/side triangular frames to which 5.6 meshes/cm netting was attached. No walleye or sauger eggs were located at any of the areas sampled, although white sucker eggs were collected from one site. Night observations were also conducted at sites where groups of ripe walleye were captured, but these attempts were unsuccessful in providing visual evidence of spawning activity.

During the spring spawning study, no significant spawning concentration was recorded for either walleye or sauger in the Bow,

Oldman and South Saskatchewan rivers in the vicinity of the Grand Forks. A total electrofishing effort of 64,468 s resulted in the capture of very few walleye and sauger. A total of 147 walleye was captured which provides a CPUE of 0.23 fish/100 s. Of these 147 fish, only 28 were female. For sauger, the total catch was 54 fish with a CPUE of 0.08 fish/100 s; of these 54 fish, 34 were female.

Spawning activity by walleye and sauger in the Grand Forks region was virtually non-existent in the spring of 1988. Environmental conditions at the beginning of the spawning season may have been factors which affected walleye and sauger spawning effort. A rapid rise in water temperatures was recorded in the spring of 1988. Water temperatures at the onset of the spawning season were above the reported preferred temperature range at which walleye and sauger spawning activity occurs. In spite of this, the majority of walleye and sauger females initially captured were gravid, but these fish were not ready to spawn. This rapid increase in water temperature, combined with unseasonally low flows may have provided unacceptable conditions for spawning.

No significant concentrations of walleye or sauger were recorded during the spawning study. The number of female fish that developed from gravid (but green), to ripe, to spawned-out gradually increased over the study period. It is suspected that the spawning effort was both small and localized with no spawning migration or generalized movements occurring. Female walleye have been reported to develop from green to ripe in a single day, and to spawn-out in one night (Colby et al. 1979). Evidence from the spawning study in the Grand Forks area suggests that the spawning effort was asynchronous, occurring in small congregations in local areas without significant pre-spawning movements by individual fish.

Walleye-Sauger Habitat Utilization Data

Habitat utilization point observations were conducted for walleye and sauger at the Grand Forks study reach (Figure 4) during the following periods: 24 to 26 June, 28 to 30 June, 18 to 22 July, 26 to 29 July, 13 to 14 September, and 17 to 18 September.

During each study period an attempt was made to collect point observation data using the technique of direct diver observation. In all instances, the turbidity in this segment of the river reduced the effectiveness of direct observation to the extent of prohibiting its use. All point observation data for walleye and sauger were collected using electrofishing techniques.

The river discharge in the study reach was measured at the onset of each study period and was re-measured with any notable (>10%) increase or decrease in flow rate. A permanent staff gauge was established in the study reach in order to monitor any changes in river discharge and to allow the development of a stage-discharge curve.

Electrofishing observations were conducted during daylight, twilight and night conditions in order to determine the complete range of habitat requirements for walleye and sauger. Both species are known to be negatively phototactic and most active during periods of low light intensity. The period of activity is often related to the turbidity of the water (Colby et al. 1979; Scott and Crossman 1973). Walleye and sauger are crepuscular or nocturnal in their feeding habits and seek greater depths or bottom features which provide shelter during daylight, particularly under low turbidity conditions (Scott and Crossman 1973).

On each day that habitat point observations were conducted, a turbidity sample was collected from the Study Area and Secchi disc reading was taken. Turbidity samples were collected in

250 ml plastic bottles which were then labelled and stored refrigerated until they could be returned to Calgary. Turbidity analysis was conducted using a Hach model 2100A Laboratory Turbidimeter which has an accuracy of ± 2.0%. Secchi disc readings were obtained by slowly lowering the disc through the water column to a point at which the disc could no longer be seen. This depth was recorded. The disc was then lowered well past this point and then slowly raised through the water column. The depth at which it could first be seen was then recorded. The actual Secchi disc reading was determined by averaging these two depths.

The total number of habitat point observations measured from the study reach for each species and life stage were as follows: 151 walleye juvenile; 144 walleye adult; 55 sauger juvenile; and 81 sauger adult. No walleye or sauger fry were observed during boat electrofishing investigations. Fork length categories used to distinguish juvenile and adult fish were developed from data collected from fish sacrificed during the spring spawning study.

During the 26 to 29 July and 13 to 15 September study periods, special efforts were made to locate walleye and sauger fry to determine if they occurred within the designated Study Area. A backpack electrofisher (Smith-Root type VII) was used to survey the shallow, low velocity areas of the study reach where dense beds of aquatic macrophytes provided cover for walleye and sauger fry. These were generally the peripheral, littoral areas of the study reach where boat electrofishing was less effective due to difficulties in maneuvering the boat. Seine hauls (using a 6.2 m x 1.1 m, 0.8-cm mesh seine net) were conducted in shallow areas in the reach where there was no submergent vegetation cover. A substantial number of young Percid fish were captured but after careful examination, these specimens were identified as yellow perch (Perca flavescens) (Nelson 1968, Norden 1961, Paetz and Nelson 1970, Scott and Crossman 1973).

Information supplied by Fish and Wildlife personnel indicated that in previous years walleye fry and in particular, sauger fry had been captured further downstream on the South Saskatchewan River near the City of Medicine Hat. During the period 15 to 16 September, electrofishing investigations were conducted within the City of Medicine Hat, as well as upstream on the South Saskatchewan River near the Town of Redcliff (Figure 7). As the required number of observations for walleye juvenile and adult life stages had at this time been completed, the purpose of these investigations was to locate walleye and sauger fry and to determine if the density of sauger juveniles and adults increased in this region where turbidity was greater than had been found in the study reach at Grand Forks. Observations of walleye fry and all life stages of sauger were to be used to provide habitat utilization data points, but since these observations would occur outside the established IFIM Study Area, habitat availability at the time of the observations would be determined by the technique of random measurements.

After a total electrofishing effort of 10,385 s, no walleye or sauger fry were captured although a large number of young yellow perch were again identified. No sauger juveniles were located and since only a few sauger adults were observed, it was decided to continue the data collection at the Grand Forks study site.

#### 5.2.2.3 Crowsnest River

On 14, 20 and 27 June, attempts were made to initiate collection of habitat utilization observations for rainbow trout in the Crowsnest River study reach. On each of these dates the turbidity levels of the river were too high to allow the use of underwater direct observations techniques. Observations of the rainbow trout fry and adult life stages were successfully conducted during the periods 12 to 15 July and 8 to 11 August.

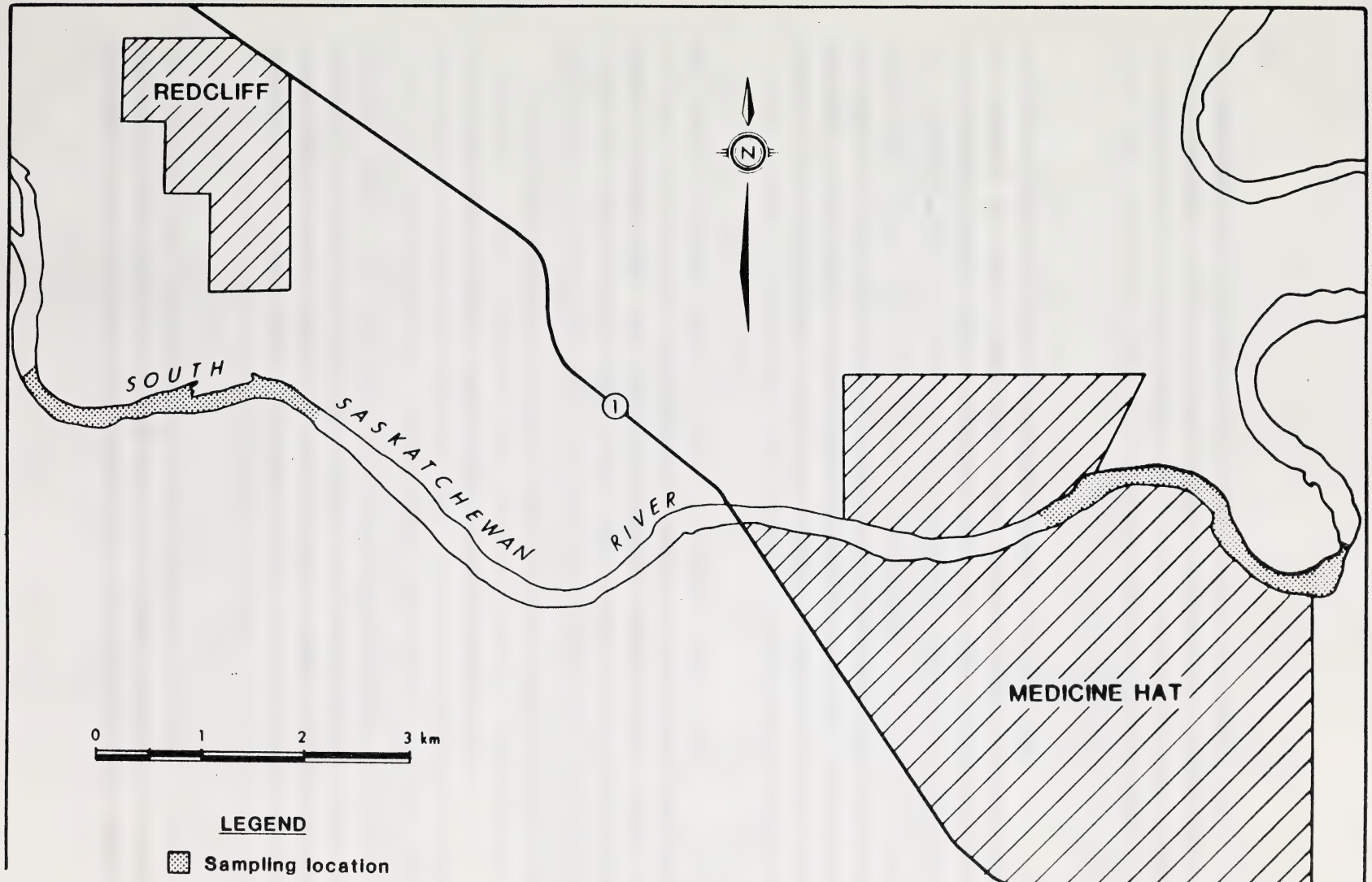



Figure 7. Locations of boat electrofisher sampling for walleye and sauger fry, 1988.

At the beginning of each study period, the discharge rate of the river was determined and a staff gauge was established to monitor the flow rate. The river discharge was re-determined if any significant (>10%) change in flow rate occurred while observations were being conducted.

During initial observation periods, diver field of vision was sufficient but limited due to moderate turbidity levels. On the afternoon of 12 July, boat electrofishing investigations were conducted within the Study Area in order to determine whether the number of direct observations recorded to that point accurately reflected the actual population of rainbow trout utilizing the Study Area. The number and distribution of observations collected while electrofishing was found to closely resemble those obtained by direct observation.

The total number of data points measured from the Crowsnest River Study Area for adult rainbow trout was 151 with 140 of these being direct observations and the remaining 11 being electrofishing observations. The fork-length range for adult rainbow trout was obtained from previous studies of the Crowsnest River rainbow trout population (O'Neil and Hildebrand 1986).

No rainbow trout fry were observed during the periods of direct observations despite diver efforts to examine all available habitat types, including low velocity potential rearing sites. Backpack electrofishing techniques were used to locate rainbow trout fry, which were found to be utilizing the shallow littoral areas of the reach with good cover. A total of 160 data points were obtained for the young-of-the-year life stage, all of which were collected by backpack electrofishing.

During the period of 17 to 22 April, the region of the Crowsnest River extending from the Todd Creek confluence upstream to near the Highway 507 bridge crossing (Figure 5) was surveyed for

rainbow trout spawning activity. Habitat measurements were conducted at a total of 152 rainbow trout redds during this survey.

### 5.2.3 Qualitative Rating of Habitat Utilization Data

In order to document the overall quality of the observations, it has been recommended that the quality of the recorded data be rated (Fernet and Walder 1986). These authors designed a rating system consisting of a scale from 1 to 5, where a rating of 1 indicates measurements conducted from direct observation in the watercourse (high quality data), 2 indicates relatively high quality data, but some information is unavailable (e.g., specimen was taken electrofishing and fish activity and depth at the time of capture is unknown), 3 corresponds to medium quality data, 4 corresponds to relatively poor quality data, and 5 indicates very poor data.

This rating system has been applied to the habitat utilization data collected from the study reaches on the Bow, Oldman and Crowsnest rivers for each life stage of each target species. Of the 1475 fish observations, 36 percent were Category 1 (high quality), 62 percent were Category 2 (relatively high quality), and 2 percent were medium quality. There were no observations recorded in the poor categories (Table 4).

The underwater direct observation technique utilized in this study was found to be extremely effective in terms of determining the instream position and activity of undisturbed fish. All data obtained using this method were rated as high quality, type 1 data. In addition, observations of spawning trout obtained using surface observation techniques were also rated as high quality data. Rainbow and brown trout spawning activity (redd excavation) is both obvious and unmistakable. The water clarity in the Bow and Crowsnest rivers during the respective spawning seasons, and the tendency for trout to spawn in relatively shallow

**TABLE 4**

**QUALITY RATING OF THE UTILIZATION DATA FOR THE CROWSNEST, BOW AND OLDMAN RIVER STUDY REACHES, 1988**

| | | | Number of Observations in Rating Category | | | |
|---|---|---|---|---|---|---|
| Study Reach | Target Species | Life Stage | 1 (high quality) | 2 (Relatively high quality) | 3 (medium quality) | Total |
| Crowsnest River | rainbow trout | Fry | - | 160 | - | 160 |
| | | Adult | 140 | 11 | - | 151 |
| | | Spawning | 152 | - | - | 152 |
| Bow River | brown trout | Fry | - | 156 | - | 156 |
| | | Juvenile | 53 | 105 | - | 158 |
| | | Adult | 18 | 87 | - | 105 |
| | | Spawning | 162 | - | - | 162 |
| Oldman River | walleye | Juvenile | - | 130 | 21 | 151 |
| | | Adult | - | 138 | 6 | 144 |
| | sauger | Juvenile | - | 51 | 4 | 55 |
| | | Adult | - | 80 | 1 | 81 |

water permitted reliable identification of fish species and activity.

Components of the data base from the Bow and Crowsnest River study reaches for life stages other than spawning were obtained using electrofishing techniques. In both study areas, a backpack electrofisher was used to collect all the observations for the fry life stage. Direct underwater observations were attempted but due to the shallow water depths inhabited by the fry, the diver was unable to maneuver without causing considerable disturbance to the fish. In addition, good cover was available in these areas used by fry, providing visual isolation. The small electrical field of the backpack electrofisher and the level of experience of the field crew allowed for the capture of fish very close to their holding position. However, since information on fish activity and fish depth were not obtainable with this technique, data from these observations have been rated as Type 2.

Factors influencing the effectiveness of electrofishing as an observation technique include: characteristics of the equipment; characteristics of the species; skill of the sampling crew; and, operating conditions (Bovee 1986). The backpack and boat electrofishing gear utilized for this study was equipped with variable output controls allowing the output to be modified for more efficient capture of different species and sizes of fish, in waters of varying conductivity. Most importantly, the electrode circuitry was equipped with a manual control switch which allowed the operator to control the activation of the electrode so that fish did not detect the approach of a constant electric field. This reduced fish avoidance behaviour so that the fish were more likely to be captured in place.

Both brown and rainbow trout are known to respond well to electrofishing gear and the field crew was experienced both with the equipment and the capture of stream salmonids. Operating

conditions were excellent in the Crowsnest and Bow rivers with conductivity levels allowing the reliable capture of fish. Use of the adjustable electrical field ensured fish were not captured from outside the observers range. Water clarity in the Crowsnest River was excellent and in the Bow River good to excellent. Data from observations obtained using boat electrofishing techniques from these two study areas was rated as Type 2.

Operating conditions were less than optimal during observation periods in the Oldman River study reach. Turbidity levels precluded the use of direct observation techniques. However, turbidity levels were generally low enough (Secchi disc visibility 1.7 to 2.2 m) to allow an observer standing on the workstation platform of the electrofishing boat a good field of view in the water column. Water with a visibility in the 1 to 2 m range is considered sufficient for use of this technique (Bovee 1986).

Experience has shown that walleye and sauger do not exhibit extensive galvanotaxis (movement within an electric field) and show minimum displacement combined with early galvanonarcosis. As a consequence, when first observed the fish was considered to be very close to its original position. Data from observations of walleye and sauger obtained while electrofishing were rated as Type 2 with the exception of data collected at the end of the 28 to 30 June study period. At this time, a severe rain storm increased turbidity levels and reduced visibility. Because fish could not be observed at depth, data from observations obtained during this time period were rated as Type 3.

### 5.2.4 Quantitative Rating of Habitat Utilization Data

The collection of an adequate sample size is the goal of any biological sampling program. Habitat use can be analyzed qualitatively using an existing sample to determine the sample size

required to attain a specified level of precision and accuracy in determining the mean. Bovee (1986) cites an equation from Platts et al. (1983) that estimates the required sample size:

$$n = \frac{t^2 s^2}{E^2}$$

where n = the required sample size

t = students t for the initial sample size - 1 degree of freedom at a specified probability level

$s^2$ = the sample variance

E = the acceptable error between the sample mean and the population mean (accuracy)

Jackle and Barrett (1988) present the same equation in a different form as being the most appropriate for IFIM needs. It should be pointed out that this formula is very dependent on the variance of the population. If a habitat use curve for a population is very broad (variance is large), the required sample size to estimate the mean accurately will be large. A narrow habitat use curve will result in lower sample size requirements. A narrow or wide habitat use curve is dependent on both the habitat available to the fish, and the subset of habitat conditions used by the fish (Bovee 1986). Therefore, a species that utilizes a variety of habitat types or a sample taken during a period of narrow habitat availability will mislead the investigator into believing that a large or small sample, respectively, is required. This quantitative approach to sample size determination must be tempered with biological knowledge.

The level of accuracy used to calculate required sample sizes was partly dependent on the mean of our samples. Substrate means were in the 4 to 7 range so the acceptable error (E) was established at $\pm$ 0.5 substrate units. Velocity and depth means were generally lower, so the acceptable error was set at 0.1 units.

In instances where the mean was less than 0.4 units, the error was set at ± 0.05 units (see Appendix II). Due to the categorical nature of the cover variable, it was not possible to analyze cover using this method. The confidence level for all analyses was established at 0.95. More precisely, this means that a sample of the calculated size (n) will have a mean that is within the bounds of the population mean ± the acceptable error (E), 95 times out of 100.

Measurements were taken at more than one flow, for some life stages in an effort to collect the sample size of 150 as outlined in the Terms of Reference for the study. The sample size observed at each flow was analyzed separately (Appendix II), but the flow that had the largest sample size is presented in text as being most representative (Table 5). The results are presented in this manner because the flow with the largest sample size would give the best estimate of the population mean and population variance. Estimates of the required sample size were compared with the total combined sample sizes which were used to calculate the preference curves.

Table 5 summarizes the information found in Appendix II. In addition, a subjective rating has been presented which combines the results of the quantitative approach with the biological knowledge of the species and life stage involved. Based on the results presented in Table 5, a sample of 219 spawning brown trout would be required to obtain a good estimate of habitat utilization. This is somewhat more than the 162 samples which were obtained. In this case, the variance for both depth and velocity were at least as large as the mean (Appendix II), hence, the large estimate for sample size requirements. Only four samples were calculated as being necessary to describe the substrate variable, suggesting that substrate particle size is more important to spawning brown trout than either depth or velocity. That is, spawning brown trout were using a very narrow range of substrate particle sizes, such that

TABLE 5
ACTUAL AND CALCULATED SAMPLE SIZES FOR DEPTH,
VELOCITY AND SUBSTRATE UTILIZATION VARIABLES

| Life Stage | Sample Type | Substrate | Depth | Velocity | Subjective Rating |
|---|---|---|---|---|---|
| Brown trout spawning | actual | 162 | 162 | 162 | fair |
| | calculated | 4 | 197 | 219 | |
| Brown trout adults | actual | 53 | 53 | 53 | fair |
| | calculated | 79 | 67 | 47 | |
| Brown trout juvenile | actual | 51 | 51 | 51 | very good |
| | calculated | 7 | 15 | 28 | |
| Brown trout fry | actual | 156 | 156 | 156 | very good |
| | calculated | 4 | 5 | 43 | |
| Rainbow trout spawning | actual | 150 | 150 | 152 | very good |
| | calculated | 7 | 3 | 9 | |
| Rainbow trout adults | actual | 166 | 168 | 168 | very good |
| | calculated | 45 | 19 | 40 | |
| Rainbow trout fry | actual | 155 | 156 | 156 | very good |
| | calculated | 8 | 6 | 10 | |
| Walleye adults (day) | actual | 110 | 110 | 110 | very good |
| | calculated | 88 | 81 | 10 | |
| Walleye adults (night) | actual | 24 | 24 | 24 | poor |
| | calculated | 48 | 85 | 23 | |
| Walleye juvenile (day) | actual | 99 | 99 | 99 | good |
| | calculated | 110 | 60 | 8 | |
| Walleye juvenile (night) | actual | 62 | 62 | 62 | good |
| | calculated | 57 | 63 | 12 | |
| Sauger adults (day) | actual | 72 | 72 | 72 | fair |
| | calculated | 165 | 48 | 2 | |
| Sauger adults (night) | actual | 9 | 9 | 9 | poor |
| | calculated | 122 | 194 | 54 | |
| Sauger juveniles (day) | actual | 40 | 40 | 40 | fair |
| | calculated | 174 | 44 | 2 | |
| Sauger juveniles (night) | actual | 16 | 16 | 16 | poor |
| | calculated | 83 | 41 | 29 | |

this distribution could be defined with confidence with as few as four samples.

Use of the sample size equation resulted in the estimate that 79 brown trout adults were required to define substrate preference, while only 53 samples were actually obtained. The variance for substrate was quite high for the juvenile and adult life stages of most species, suggesting that there was not a strong preference for any particular substrate for these life stages, which is logical. The calculated sample sizes required to define depth and velocity preferences were slightly higher for brown trout adults (67 and 47 respectively), which is relatively close to the 53 observations which were made (Table 5).

There were a maximum of 51 samples obtained at a single flow for brown trout juveniles. Calculated sample sizes for all variables were much smaller than this number. Only 28 samples were apparently required for a good estimate of habitat use. This was also true for brown trout fry: 156 samples were obtained, but a total of only 42 were required for good estimates of habitat preference. Calculated sample size requirements for the substrate and depth curves were very low (4 and 5 respectively), because the brown trout fry were consistently found in very similar depths and substrate types and the variance for those variables was therefore quite low. Velocity, on the other hand, was based on mean column velocity, which often differed considerably from the nose velocity for fry. This would explain the greater variance in velocity (Appendix II), resulting in a relatively large estimate of sample size requirements (n=43).

A total of 150 samples was obtained for the rainbow trout spawning life stage, while the mathematical analysis suggested that only 7 samples were required for the 95% confidence in estimating substrate utilization. The sample requirements for spawning depths and velocities were estimated at 3 and 9 samples, respectively, due

to the very small variances between samples. Therefore, the sample was more than sufficient to obtain good estimates of habitat utilization. A total of 168 rainbow trout adult observations was obtained, and the equation estimated that only 45 were required for good estimates of habitat use. Rainbow trout fry also appeared to be quite specific in their choice of habitat. In excess of 150 samples were obtained but a maximum of 10 was calculated as being necessary to yield good estimates of habitat use.

A sample of 88 walleye adults during the day was required to give a good estimate of preference for substrate, 81 for depth and only 9 for velocity. A total of 110 samples was actually obtained. A sufficient number of observations was also collected for both day and night samples of walleye juveniles, according to the estimate of sample size requirements. The night samples for walleye adults however, numbered only 24 and the calculated sample size was 85, based on the depth variable.

The sauger juvenile and adult night sample sizes were lower than the estimated sample sizes required to define habitat preferences. Actual sample sizes were 9 and 16, respectively. The habitat preferences identified with the night sample data for sauger was not used in the analysis due to the small sample size available.

A total of 72 samples was obtained for sauger adults during the day. For both depth and velocity, this exceeded the estimated sample size requirement. However, the calculated sample size for substrate was 165. As mentioned earlier, substrate was thought to play a minor role in habitat selection for life stages other than spawning. This was also the case for the sauger juvenile day samples. The actual number of depth and velocity samples appeared to be adequate based on the calculated sample size. Only the substrate sample size was smaller than that the mathematical analysis suggested as being required to give a representative habitat utilization curve.

### 5.2.5 Development of Habitat Preference Curves

Habitat use for all life stages except walleye and sauger fry and spawning was determined from point observations of fish. Substrate data were quantified as recommended by Fernet and Walder (1986). Cover data were quantified as distance to nearest cover. More than one cover type could be recorded for a given fish observation.

Habitat availability information was determined from IFIM modelling of the study reaches where the fish observations were gathered, except for the life-stages mentioned above. The rainbow trout spawning data were not collected in the IFIM study reach so a systematic sampling of a series of points in surrounding habitat was used to determine habitat availability. Cover data were quantified as for point observations of fish.

The basic method used to develop the univariate habitat preference curves for velocity, depth and substrate was the division of the normalized frequency distribution for habitat use by the normalized frequency distribution for habitat availability. Sturges equation (1926, as cited in Cherlak and Garcia 1988) was used to derive interval size of the habitat use frequency distributions, as recommended by Cherlak and Garcia (1988). The Sturges equation is:

$$C = R/(1 + 3.322 (\log N))$$

Where: C = the optimal interval of bin size
R = the range of values
N = the number of observations

The same intervals were used to derive the habitat availability curves.

The method outlined above was employed where all fish observations were collected at a single flow. When fish

observations were collected at more than one flow, Sturges equation was applied to the data from the flow with the greatest number of fish observations. The normalized frequency distributions for use and availability were derived separately from each flow and separate preference distributions were calculated. Preference distributions were combined into a single average preference distribution weighted by the number of fish observations at each flow.

Development of the habitat preference curves for cover was somewhat different from that described above. Cover is a categorical variable by nature, so Sturges Rule was not used to derive interval size. Instead intervals were defined by the cover categories. Cover use was recorded as distance to cover. During analysis of each life stage, use of each cover type was determined by an enumeration of all fish within 1 m (0.25 m for fry) of a given cover type. These data were normalized by dividing by the total of all enumerations by the total for the largest category.

Cover availability for rainbow trout spawning was calculated as described for cover use. Cover availability for other life stages was determined from IFIM modelling of the study reaches. Cover availability data were collected as percent of each IFIM cell. This percentage was converted to area of the study reach for each cover type at each discharge of interest. Availability was then normalized by dividing each cover type area by the largest individual cover area. Preference was then determined as described above.

Subsequent to these procedures, curve development methodology was uniform. Initial preference curves were developed by connecting midpoints of the preference histograms. All curves were then compared to available data collected by other researchers. In some cases, low habitat use in a frequency interval with very low availability gave unrealistically high

preferences for that interval. These cases were removed from the distribution used to derive preference curves. For the majority of curves where data were considered reliable (e.g., 150 fish observations were collected at a singe flow with a good diversity of habitat types available), the curve followed the data closely. Where there were inconsistencies in the data (e.g., poor habitat availability, few observations, large disagreements with other researchers, anomalous distributions), curve development involved greater reliance on habitat preference information from previous work in the area and from other researchers. Where necessary, therefore, curves were based on professional judgement as well as quantitative information. The availability, utilization and preference data employed in the study are presented in Appendix IV.

#### 5.2.6 Transferability of Walleye and Sauger Preference Criteria

One component of the present study involved the evaluation of transferability of walleye and sauger habitat preference criteria to the upstream region of the Oldman River. However, sampling within the Oldman River study reaches 1 and 2 on 9 May and 19 September, 1988 did not result in the capture or observation of any walleye or sauger life stage in this region of the Oldman River. A comparison of the habitats used by walleye and sauger in the upper regions of the river was therefore not possible. However, as the juvenile and adult habitat preferences defined in this study were developed from the Oldman River, transferability of these criteria in the present study are not an issue.

### 5.3 ANALYSIS OF HABITAT AVAILABILITY WITH DISCHARGE IN THE OLDMAN RIVER

The determination of the relationship between microhabitat availability and streamflow was facilitated with the

use of the PCSIM software. The hydraulic model employed in the analysis was IFG4. Water surface elevations for simulated discharges were determined from the stage/discharge relationships developed from direct measurement of a series of flows at each transect within the six study reaches. The hydraulic data decks and the stage/discharge relationships for each transect were forwarded for technical review to Ron Bothe of the Hydrology Branch, Technical Services Division, Alberta Environment prior to using the data.

The habitat preference criteria used in the HABTAT model were as follows. The rainbow trout juvenile preferences were those reported for the Oldman River downstream of the damsite (Fernet and Matkowski 1986a). The walleye spawning and fry habitat preferences were those reported for use with IFIM by McMahon et al. (1984). These data included utilization information for walleye fry (depth, velocity, substrate) and spawning (depth, velocity), and category one (literature based) data for walleye spawning substrate. The walleye spawning preference information prepared from the data provided by Dr. Liaw of the Saskatchewan Fisheries Laboratory supported the spawning information from McMahon et al. (1984).

The sauger habitat preference information for the spawning and fry life stages was taken from Crance (1986). This information was developed through the use of the Delphi technique (i.e., consensus among experts), rather than any field measurements.

The habitat preference criteria employed in the analysis for the remaining species and life stages (i.e., rainbow trout spawning, fry, adult, walleye and sauger juvenile and adult, brown trout spawning, fry, juvenile, adult) were those developed during the present study.

## 5.4 IDENTIFICATION OF INSTREAM FLOW NEEDS FOR FISH

The development of a suitable flow regime for the protection of the fishery resource involved two components: the identification of a technique for determining instream flow needs for fish which was acceptable to both Alberta Environment and the Fish and Wildlife Division of Alberta Forestry, Lands and Wildlife; and, use of the technique for the river segments downstream of the Oldman River Dam.

### 5.4.1 Methodology

There are a number of techniques which have been employed to interpret the product of the PHABSIM analysis, which is the habitat versus flow relationship [e.g., Bovee (1982) - optimization techniques, habitat duration curves, effective habitat time series; Sale et al. (1981) - habitat frequency analysis; Geer (1987) - mathematical analysis based on composite habitat values]. Most analytical techniques are employed to determine the impact of a projected flow regime on fisheries, as opposed to identifying a suitable flow regime for protection of the fisheries resource.

In Alberta, water planning is often carried out with the use of a water balance model, the input to which is a variety of user demands. As the instream flow needs for fish are one of these demands, target flows for fishery protection are required. In order to identify the fisheries flow recommendations, the Fish and Wildlife Division has developed an approach termed the "Fish Rule Curve" (Locke 1988). This analytical technique, although still in the developmental phase, recognizes the impracticality of identifying a single minimum streamflow requirement for fish.

The use of a minimum streamflow value is dangerous if this value is based on the flow rate which just avoids fish mortality. Although no mortality may occur at the identified flow

rate, there will not likely be any growth of the fish population if the aquatic habitat is maintained at a bare minimum. An alternative for protection of the resource is a minimum flow recommendation that provides moderately good habitat for fish. However, when compared to historic flow records, this flow may not always be available, which will cause the water balance model to fail.

One solution previously employed in Alberta was the identification of failure, poor, fair, good and optimum flow rates for fish. The return rate of flows in these categories was based on the frequencies which would have existed with a naturalized hydrograph (Fernet and Matkowski 1986c). The Fish and Wildlife Division had improved on this method of analysis with the Fish Rule Curve. Flows associated with optimum (maximum habitat availability within the discharge range for the watercourse), fair (median habitat availability) and minimal habitat availability (minimum amount of habitat which is judged to be required to maintain the population) are identified for the fauna present in the watercourse, based on the habitat versus flow relationship. The analysis is based on the most important, or most critical life stage of the species of greatest interest. The entire array of life stages present are then examined to ensure the flows associated with each recommendation (i.e., optimal, fair, minimal) are not adversely affecting any of the other life stages present.

The flow value for optimal habitat is attributed to wet years, or 20 percent exceedence flows (i.e., flows which are equalled or exceeded two years out of ten). The flow which provides the fair habitat value is attributed to an average year (50 percent exceedence flow), while the minimal habitat value is attributed to a dry year (80 percent exceedence flow). These values are then plotted on a natural flow duration curve. If the flow associated with the minimal habitat value is greater than 80 percent exceedence flow, the requested instream flow for fish is

reduced to match the flow duration curve at this point (Locke 1988).

The rationale for reducing the flow request during the drier years is that the fishery had evolved in a manner which would enable survival during the dry years, or the fishery would not exist. This does not mean that the instream flow recommendation is condoning occasional fish kills, but rather is recognizing that this is a natural occurrence. Obviously, if upstream storage exists, some flow augmentation is desirable if the water is available. However, in the event that the Fish Rule Curve follows the flow duration curve during dry periods, it also means that during the 80 and 90 percent exceedence flow years no storage or diversion of the water in the system is allowed. The resultant instream flow recommendation is further adjusted, if required, to include any water quality issues that may exist as a result of water quality deterioration in the watercourse.

A workshop was conducted on 13 and 14 June, 1988, which was attended by Fish and Wildlife Division personnel, Dr. T. Hardy and EMA personnel, to discuss the advantages and disadvantages of the various techniques for determining instream flow needs for fish. It was concluded that use of the optimization matrix (Bovee 1982) and the Geer technique (Geer 1987) were useful tools, but the method with the greatest suitability for the identification of instream flow requirements in Alberta was the Fish Rule Curve. Dr. T. Hardy was therefore directed to create programs for the optimization analysis, the Geer analysis and the Fish Rule Curve, which would interface with the PCSIM programs for use on an IBM or IBM-compatible microcomputer. Dr. Hardy was also directed to write programs which would enable a time-series analysis of flow records and water balance model output. Copies of the programs REFORMAT, EDITOR, HABINDEX and TRANSECT, which were developed by Enhytec Consulting Ltd. for Planning Division, Alberta Environment, were

provided to Dr. Hardy, for use in the development of the software package.

The software created by Dr. Hardy was employed to develop Fish Rule Curves for the months of April through November (on a monthly time-step) for each of the six river segments between the Oldman River Dam and the confluence with the Little Bow River. The Fish Rule Curve was developed on the basis of a re-constructed "natural" hydrograph (i.e., estimate of natural flows) for the Oldman River at the points below LNID (1912-1986), above the Belly River confluence (1966-1986) and at Lethbridge (1912-1986). The naturalized hydrograph for the period 1966 to 1986 was provided by the Hydrology Branch, Technical Services Division, Alberta Environment. For the evaluation of river Segments 5 and 6, the recorded hydrograph (1912 to 1986, extended by the Hydrology Branch) from the Water Survey of Canada station at Brocket (WSC Station No. 05AA024) was employed. Historic water abstractions upstream of LNID were judged to be negligible. The hydrologic records employed in this analysis and the periods of record are summarized on Table 6.

### 5.4.2 Analysis of Habitat Availability

Habitat duration curves were created for each scenario for the purpose of evaluating habitat availability under various flow regimes (i.e., recorded hydrograph, naturalized hydrograph, water balance model output). This analysis was facilitated through the use of the software which combined the flow record or simulation with the relationship between flow and habitat availability to create habitat time-series relationships.

The analysis of habitat availability was conducted without consideration for the importance of cover for the target species. Both rainbow trout and brown trout are dependent on the

TABLE 6

**RECORDED, NATURALIZED AND SIMULATED FLOW RECORDS (MEAN MONTHLY FLOW, $M^3/S$) EMPLOYED IN ANALYZING HABITAT DURATIONS, OLDMAN RIVER**

| | | Station (Node) Employed to Represent Flows in River Segment | | | | | |
|---|---|---|---|---|---|---|---|
| Flow Type | Period of Record | 1 | 2 | 3 | 4 | 5 | 6 |
| Naturalized | 1912-1986 | Oldman at Lethbridge | N/A[a] | Oldman below LNID | Oldman below LNID | Oldman at Brocket | Oldman at Brocket |
| | 1966-1986 | | N/A | | | | |
| Recorded | 1911-1986 | Oldman at Lethbridge | Oldman above St. Mary Confluence | | | | |
| | 1912-1986 | | | | | Oldman at Brocket | Oldman at Brocket |
| | 1966-1986 | | | Oldman above Belly Confluence | Oldman below LNID | | |
| ODO5[b] | 1928-1986 | Oldman at Lethbridge | N/A | Oldman below LNID | Oldman below LNID | Oldman below Pincher Creek | Oldman below dam |

[a] N/A = Not Available

[b] ODO5 = Current Water Balance Model Simulation

availability of suitable instream and offstream cover (Raleigh et al. 1984, Raleigh et al. 1986). The only cover present in the Oldman River was that provided by the substrate (i.e., there were essentially no undercut banks, overhanging bank vegetation, root wads, etc.). Therefore, if habitat availability for rainbow and brown trout was evaluated based on existing cover in the river, the result would be essentially no habitat under all flow scenarios. The analysis proceeded, therefore, on the basis of analyzing depth, velocity and substrate, with the understanding that the cover deficiency would be overcome through habitat enhancement (see Section 5.5). Walleye and sauger are not as dependent on cover, and the use of depth, velocity and substrate criteria was judged to be a fair evaluation of habitat quality for these species.

The calculation of the habitat time-series relationship provides the mean monthly habitat values (as mean monthly flow values were employed in the analysis) for each life stage of interest for the period of record. These results were then compiled to produce habitat duration tables, which are comparable to flow duration tables in that they summarize the percent of time habitat values were equalled or exceeded during the period of record.

The initial analysis involved the development of habitat duration information for brown and rainbow trout in river Segments 4, 5 and 6 (exclusive of cover), and walleye and sauger in Segments 1, 2 and 3. The brown trout analysis was extended to the coolwater region of the river (i.e., Segments 1, 2 and 3) as the water quality analysis revealed suitable temperatures were anticipated for this species at least as far downstream as the confluence with the Little Bow River (HydroQual 1990).

Presentation of the results becomes problematic due to the large number of habitat duration analyses. The area beneath the habitat duration curves was therefore calculated by river

segment for each life stage, monthly time-step and flow scenario to enable a representation of habitat availability during the open-water period. These data were still cumbersome, as the interpretation of differences between the flow regimes involved examining between 8 and 14 graphs for each river segment. Therefore, for analytical purposes, the Geer approach (Geer 1987) was employed.

The Geer technique involves use of the life stage periodicities of the target organisms, termed biologically significant periods (BSP's). The BSP's are the spring spawning periods (1 April through 15 June for rainbow trout; 1 April through 31 May for walleye and sauger), the summer period (1 June or 15 June through 30 September), and the fall spawning period (1 October through 30 November). For each BSP, the various life stages of the target species are weighted according to management goals. Through the use of the habitat versus flow relationships and the relative weightings, a single relationship is developed for each BSP. The procedure essentially involves creating a "composite" fish, with a single habitat versus flow relationship. The weightings employed for each of the life stages of the target species for each biologically significant period and river segment in this analysis are summarized in Table 7.

The habitat availability for the assemblage of life stages of the target species as represented by the Geer analysis was then determined for the natural, recorded and OD05 flow regimes at the river segments where all the required flow records were available (i.e., all segments except 2). A habitat duration graph was prepared for each BSP at these river segments, the area under each graph calculated, and the areas under the curves plotted by month for each river segment. This method of presentation enables a direct comparison of an indication of habitat availability for

TABLE 7

WEIGHTINGS EMPLOYED IN DEVELOPING THE HABITAT VERSUS FLOW RELATIONSHIP FOR THE COMPOSITE FISH

## STUDY SECTIONS 1, 2 AND 3

**BSP 1**

| Species | Lifestage | |
|---|---|---|
| WALLEYE | JUVENILE | WEIGHTING FACTOR = 5 |
| WALLEYE | ADULT | WEIGHTING FACTOR = 5 |
| WALLEYE | SPAWNING | WEIGHTING FACTOR = 20 |
| WALLEYE NIGHT | JUVENILE | WEIGHTING FACTOR = 5 |
| WALLEYE NIGHT | ADULT | WEIGHTING FACTOR = 5 |
| SAUGER | JUVENILE | WEIGHTING FACTOR = 5 |
| SAUGER | ADULT | WEIGHTING FACTOR = 5 |
| SAUGER | SPAWNING | WEIGHTING FACTOR = 30 |
| BROWN TROUT | FRY | WEIGHTING FACTOR = 1 |
| BROWN TROUT | JUVENILE | WEIGHTING FACTOR = 5 |
| BROWN TROUT | ADULT | WEIGHTING FACTOR = 5 |

**BSP 2**

| Species | Lifestage | |
|---|---|---|
| WALLEYE | FRY | WEIGHTING FACTOR = 1 |
| WALLEYE | JUVENILE | WEIGHTING FACTOR = 10 |
| WALLEYE | ADULT | WEIGHTING FACTOR = 10 |
| WALLEYE NIGHT | JUVENILE | WEIGHTING FACTOR = 20 |
| WALLEYE NIGHT | ADULT | WEIGHTING FACTOR = 20 |
| SAUGER | FRY | WEIGHTING FACTOR = 20 |
| SAUGER | JUVENILE | WEIGHTING FACTOR = 10 |
| SAUGER | ADULT | WEIGHTING FACTOR = 10 |
| BROWN TROUT | FRY | WEIGHTING FACTOR = 1 |
| BROWN TROUT | JUVENILE | WEIGHTING FACTOR = 20 |
| BROWN TROUT | ADULT | WEIGHTING FACTOR = 10 |

**BSP 3**

| Species | Lifestage | |
|---|---|---|
| WALLEYE | FRY | WEIGHTING FACTOR = 1 |
| WALLEYE | JUVENILE | WEIGHTING FACTOR = 10 |
| WALLEYE | ADULT | WEIGHTING FACTOR = 10 |
| WALLEYE NIGHT | JUVENILE | WEIGHTING FACTOR = 20 |
| WALLEYE NIGHT | ADULT | WEIGHTING FACTOR = 20 |
| SAUGER | FRY | WEIGHTING FACTOR = 20 |
| SAUGER | JUVENILE | WEIGHTING FACTOR = 10 |
| SAUGER | ADULT | WEIGHTING FACTOR = 10 |
| BROWN TROUT | FRY | WEIGHTING FACTOR = 1 |
| BROWN TROUT | JUVENILE | WEIGHTING FACTOR = 20 |
| BROWN TROUT | ADULT | WEIGHTING FACTOR = 10 |
| BROWN TROUT | SPAWNING | WEIGHTING FACTOR = 40 |

## STUDY SECTIONS 4, 5 AND 6

**BSP 1**

| Species | Lifestage | |
|---|---|---|
| RAINBOW TROUT | JUVENILE | WEIGHTING FACTOR = 1 |
| RAINBOW TROUT | ADULT | WEIGHTING FACTOR = 10 |
| RAINBOW TROUT | SPAWNING | WEIGHTING FACTOR = 20 |
| BROWN TROUT | FRY | WEIGHTING FACTOR = 2 |
| BROWN TROUT | JUVENILE | WEIGHTING FACTOR = 20 |
| BROWN TROUT | ADULT | WEIGHTING FACTOR = 20 |

**BSP 2**

| Species | Lifestage | |
|---|---|---|
| RAINBOW TROUT | FRY | WEIGHTING FACTOR = 1 |
| RAINBOW TROUT | JUVENILE | WEIGHTING FACTOR = 1 |
| RAINBOW TROUT | ADULT | WEIGHTING FACTOR = 10 |
| BROWN TROUT | FRY | WEIGHTING FACTOR = 2 |
| BROWN TROUT | JUVENILE | WEIGHTING FACTOR = 20 |
| BROWN TROUT | ADULT | WEIGHTING FACTOR = 20 |

**BSP 3**

| Species | Lifestage | |
|---|---|---|
| RAINBOW TROUT | FRY | WEIGHTING FACTOR = 1 |
| RAINBOW TROUT | JUVENILE | WEIGHTING FACTOR = 1 |
| RAINBOW TROUT | ADULT | WEIGHTING FACTOR = 10 |
| BROWN TROUT | FRY | WEIGHTING FACTOR = 2 |
| BROWN TROUT | JUVENILE | WEIGHTING FACTOR = 20 |
| BROWN TROUT | ADULT | WEIGHTING FACTOR = 20 |
| BROWN TROUT | SPAWNING | WEIGHTING FACTOR = 40 |

each month during the period of record for the various flow regimes. The area under the curves for the natural, recorded and OD05 flow regimes provides a unitless measure for comparison of habitat availability.

## 5.5 FACTORS LIMITING FISHERY PRODUCTIVITY AND MITIGATION MEASURES

The target species for fisheries management downstream of the Oldman River Dam were identified as rainbow trout, brown trout, walleye and sauger. With reference to the trout species, it was recognized that little or no habitat utilization by these species presently occurs in the region of the Oldman River downstream of the damsite. Therefore, the provision of water alone may not be sufficient to create fisheries for these species. The concern regarding walleye and sauger was not as prominent, as these species are native to the lower reaches of the river.

Two methods were employed to identify habitat limitations for the target species. It was readily apparent from previous experience on the Oldman River that insufficient cover was available for the trout species. This limitation was therefore identified. The cover preferences developed for the life stages of brown trout in the Bow River, and the fry, adult and spawning life stages of rainbow trout in the Crowsnest River provided the necessary information on the suitability of various cover types for these species.

No cover preference information was available for rainbow trout juveniles. This habitat variable was not addressed in the previous investigation of this life stage when habitat preferences were identified in the Oldman River (Fernet and Matkowski 1986a). Cover preference criteria for the rainbow trout juvenile life stage were prepared from data collected on this life stage in the transferability study carried out in the Crowsnest River (See

Appendix I). The data used to develop the cover habitat preferences for all life stages was also examined, and the abundance of each cover type was determined. These data were used as targets for the amounts of each cover type to be created based on the assumption that the Bow and Crowsnest rivers provided good trout habitat.

The second technique employed to identify habitat limitations was an examination of the relationship between discharge rate and habitat availability (excluding cover) for each life stage in each river segment. It is apparent from these relationships which life stages are limiting. The HABTAT model was then run using the habitat preference criteria for these life stages, while employing the option to identify the relative suitability of each cell in terms of depth, velocity and substrate, as well as calculating the WUA for each cell. The model was run for the range of flows under consideration for each study segment. Through examination of the model output, the factor or combination of factors which were limiting usefulness of the habitat were identified. The creation of habitat to enhance these limiting features was then requested. The suitability of alternative habitat enhancement features in meeting the requirements of the limiting life stages were identified from the habitat preference criteria developed or employed in this study.

As the effectiveness of the habitat mitigation structures will be dictated in part by the flows experienced, the design flows specified for the structures were within the range anticipated given the most recent water balance model simulation (OD05) and the instream flow requests as defined by the Fish Rule Curve.

The River Engineering Branch designed various types of habitat enhancement structures to overcome the limiting characteristics in each study segment. The procedure which was employed typically involved adding a series of new transects to

each IFG4 data deck at locations where mitigation structures were under consideration. The data decks were then recalibrated by River Engineering and run by EMA without the structures in place. The results formed the baseline condition against which changes in habitat availability would be compared. The River Engineering Branch then incorporated the design changes into the IFG4 data decks. These data decks were re-run through the HABTAT model, and the projections for habitat availability with flow compared to the baseline condition. This procedure was iterive, until the desired level of mitigation was achieved within the flow range anticipated for the individual river segments.

A separate report has been prepared on this aspect of the instream flow study, which is presented in Appendix III.

## 5.6 FLUSHING FLOW REQUIREMENTS

Streamflow regulation which involves the removal of peak flows may affect stream sediment transport, culminating in overall sediment accumulation in the system (Reiser et al. 1985). If the periodic removal or flushing of sediment does not occur, the resultant sediment accumulation may have negative effects on the aquatic resources of the system.

In order to determine if sediment accumulation was a potential problem downstream of the Oldman River Dam, a determination of the need for periodic scouring of the river was conducted. The first issue addressed in the determination of the need for flushing flows was the relative sensitivity of the important fish species and their life-history stages to sediment deposition. The fish species of primary concern in the coldwater region of the river, between the damsite and the transition zone to coolwater habitat, are the salmonids. Four trout species [rainbow, brown, cutthroat (Oncorhynchus clarki), bull (Salvelinus confluentus)] and two whitefish species [mountain, lake (Coregonus

clupeaformis)] presently occur within this region of the river. The sport species in the coolwater region of the river include walleye, sauger, northern pike (Esox lucius), mooneye (Hiodon tergisus), goldeye (H. alosoides) and lake sturgeon (Acipenser fulvescens) (Fernet and Matkowski 1986a).

The salmonids as a group are the most sensitive to the potential effects of sediment deposition downstream of the damsite. Inverse relationships exist between the quantity of fines and egg survival/fry emergence for salmonids (Reiser et al. 1985). Spawning, egg incubation and fry emergence are the life stages which are most sensitive to sediment deposition, although the infilling of pools used for summer rearing and overwintering habitat is also an issue (Reiser et al. 1985). Therefore, the need to address flushing flow requirements downstream of the Oldman River Dam was identified. The issues of magnitude, duration and frequency of flushing flows was addressed by J.N. MacKenzie Engineering Ltd. (1989).

## 5.7 WATER QUALITY

Water quality issues downstream of the Oldman River Dam were addressed by the Water Quality Working Group. For the purpose of identifying instream flow requirements for fish, the recommendations of the Working Group generated to date were incorporated into streamflow recommendations for fish.

The use of IFIM for developing streamflow recommendations is only applicable to the open-water months, as the hydraulic model will not accommodate ice-cover conditions, and the habitat preference criteria which have been developed do not apply to overwintering behaviour. Streamflow recommendations for the winter months were largely based on the recommendations of the Water Quality Working Group for the quantity of water required to maintain water quality standards (primarily dissolved oxygen concentrations) during the winter months.

# 6.0 RESULTS

## 6.1 LOW FLOW MEASUREMENTS

Hydraulic measurements were conducted on the Oldman River at Segments 5 and 6 to provide modelling capabilities within the flow ranges of 4 to 20 $m^3/s$. The data were formatted for use with a single-flow IFG4 model, and calibrated to the point that all velocity adjustment factors fell within the 'good' range (Milhous et al. 1984). The water surface elevations recorded at each transect were added to the stage-discharge relationship for Segments 5 and 6.

## 6.2 HABITAT PREFERENCE CRITERIA

### 6.2.1 Habitat Preference Curve Development

The habitat preferences for depth, velocity, substrate and cover developed for the brown trout spawning, fry, juvenile and adult life stages are summarized in Figures 8 through 11. Comparable criteria are presented for rainbow trout in Figures 12 through 15. The habitat preferences noted in Figure 12 for depth, velocity, and substrate for rainbow trout juveniles are those previously developed from the Oldman River while the cover criteria were developed from measurements made in the Crowsnest River (See Appendix I).

The preference criteria employed for sauger are illustrated in Figures 16 through 19, of which the juvenile and adult information was developed from the lower Oldman River while the source of the spawning and fry information was Crance (1986). The substrate preference curves were recoded to conform with the weighted average index format which was being used in this analysis. Cover was not a criterion considered by Crance (1986),

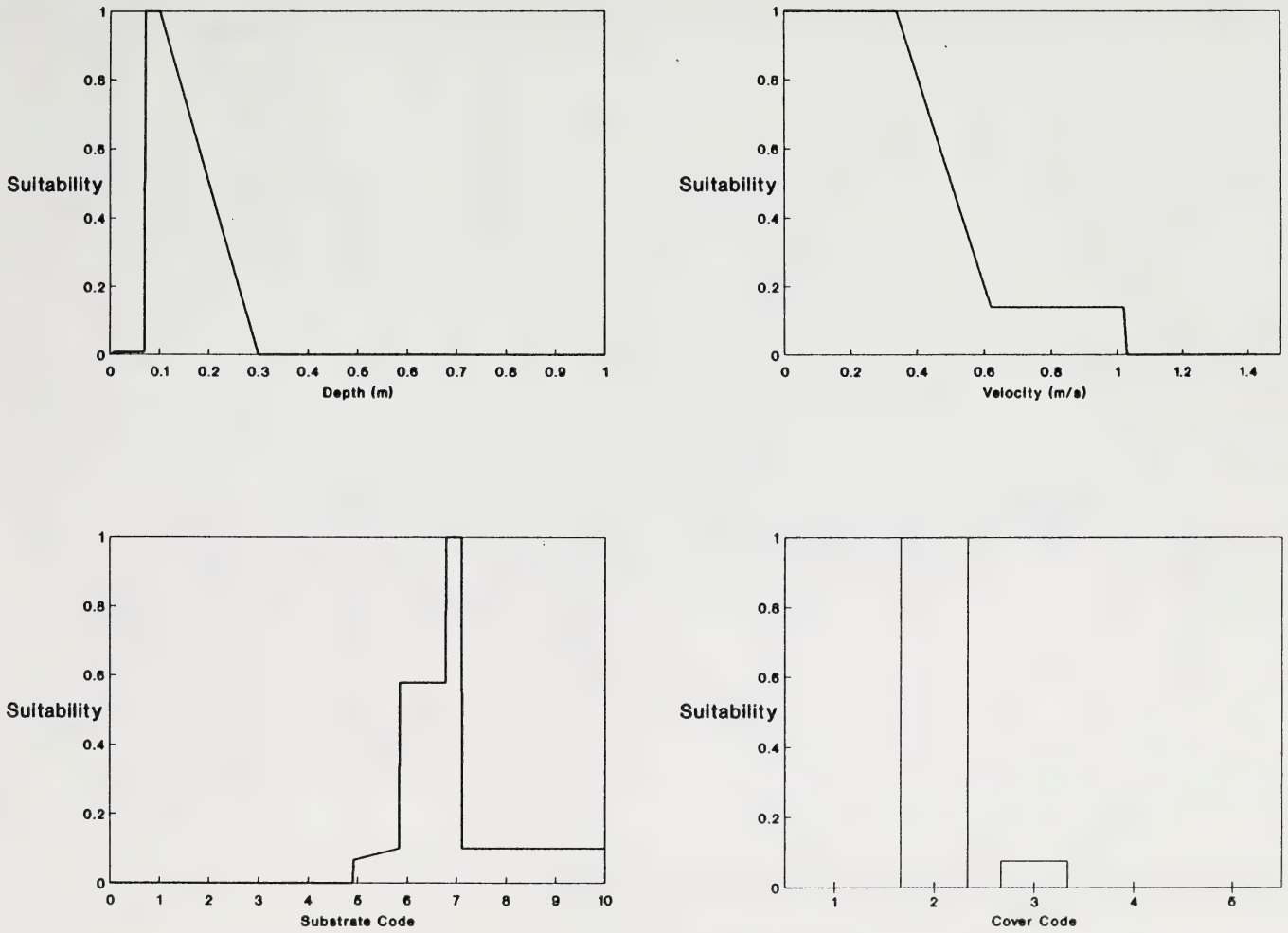



Figure 8. Brown trout fry habitat preference curves.

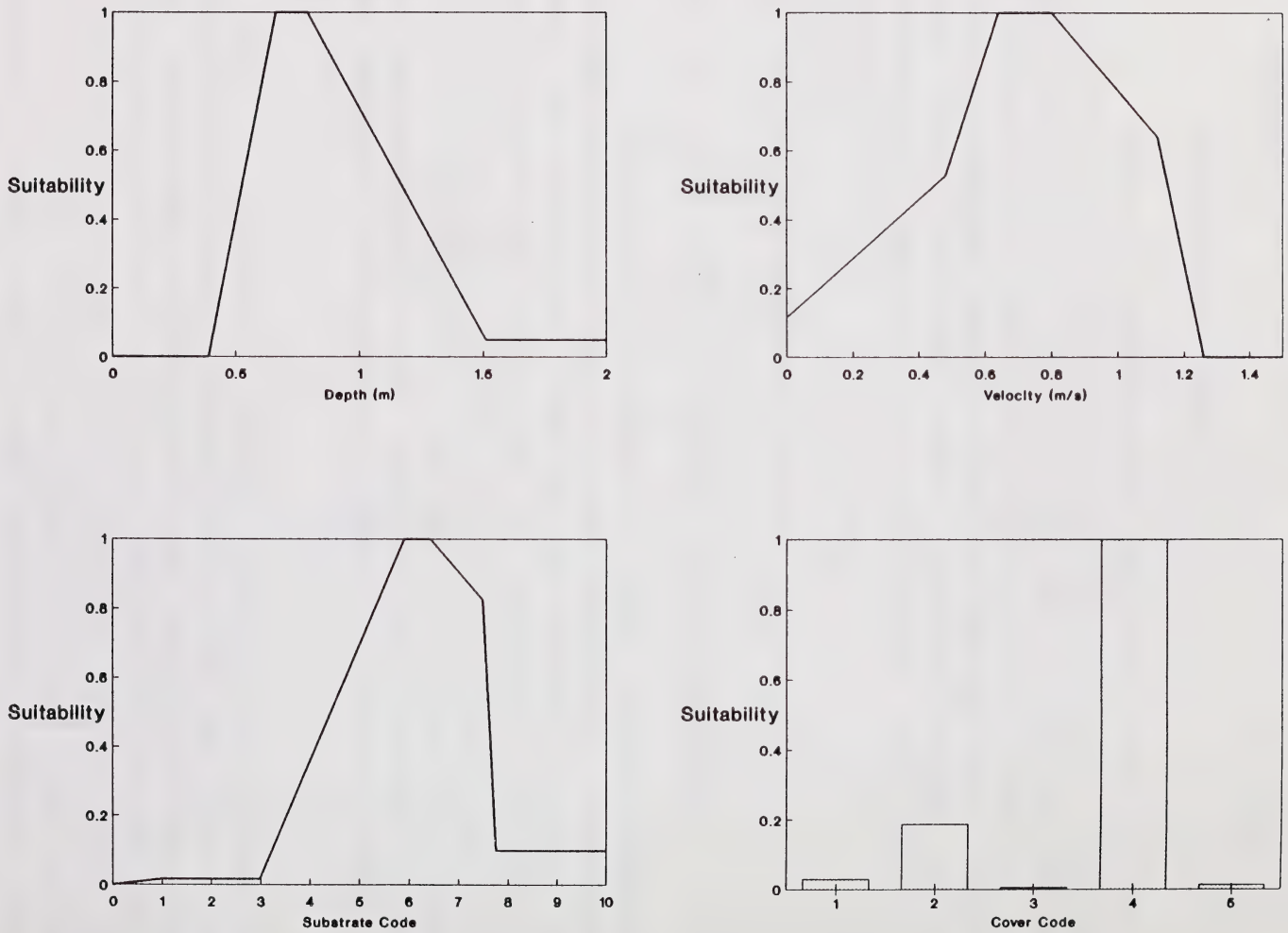



Figure 9. Brown trout juvenile habitat preference curves.

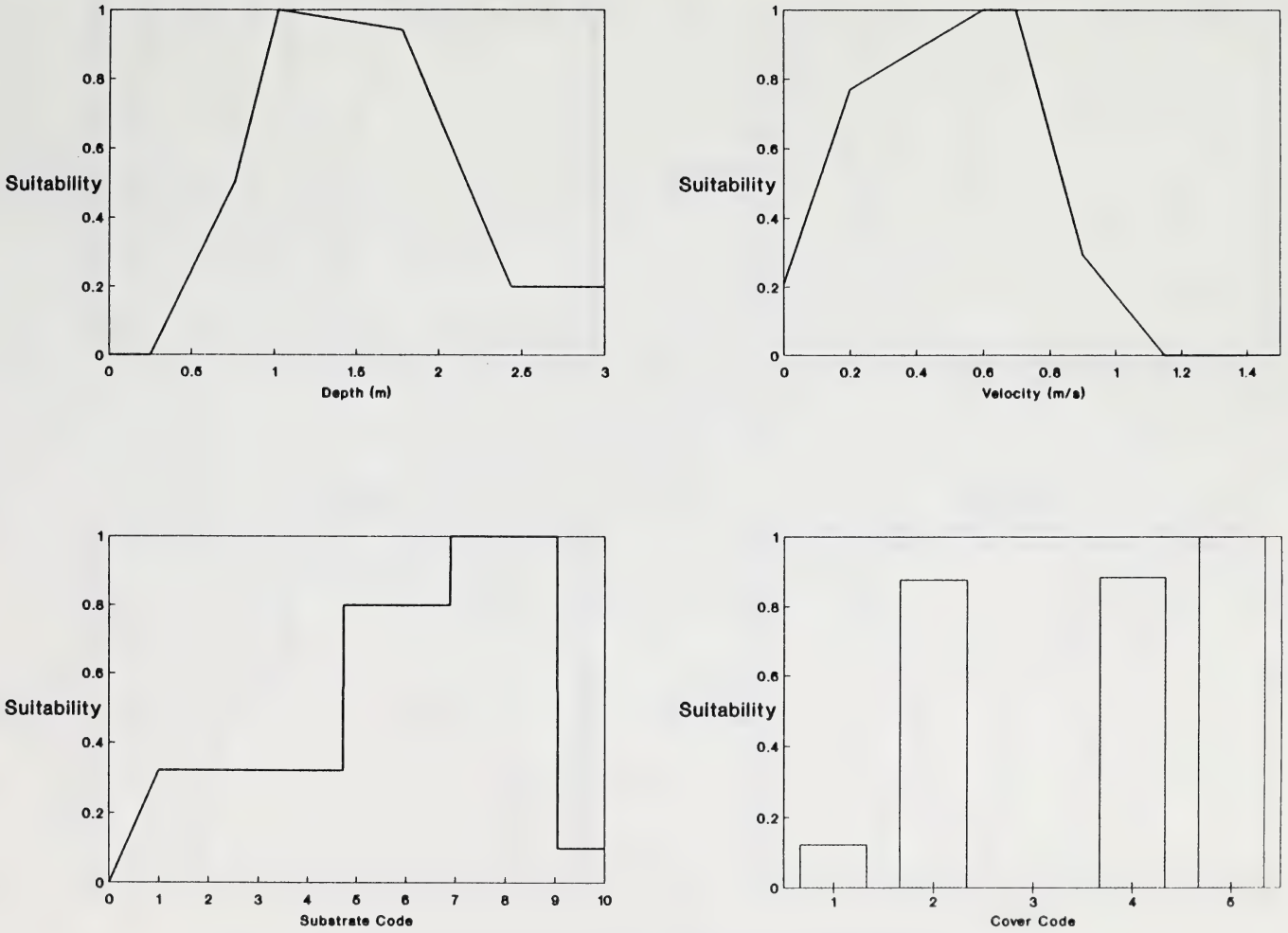



Figure 10. Brown trout adult habitat preference curves.

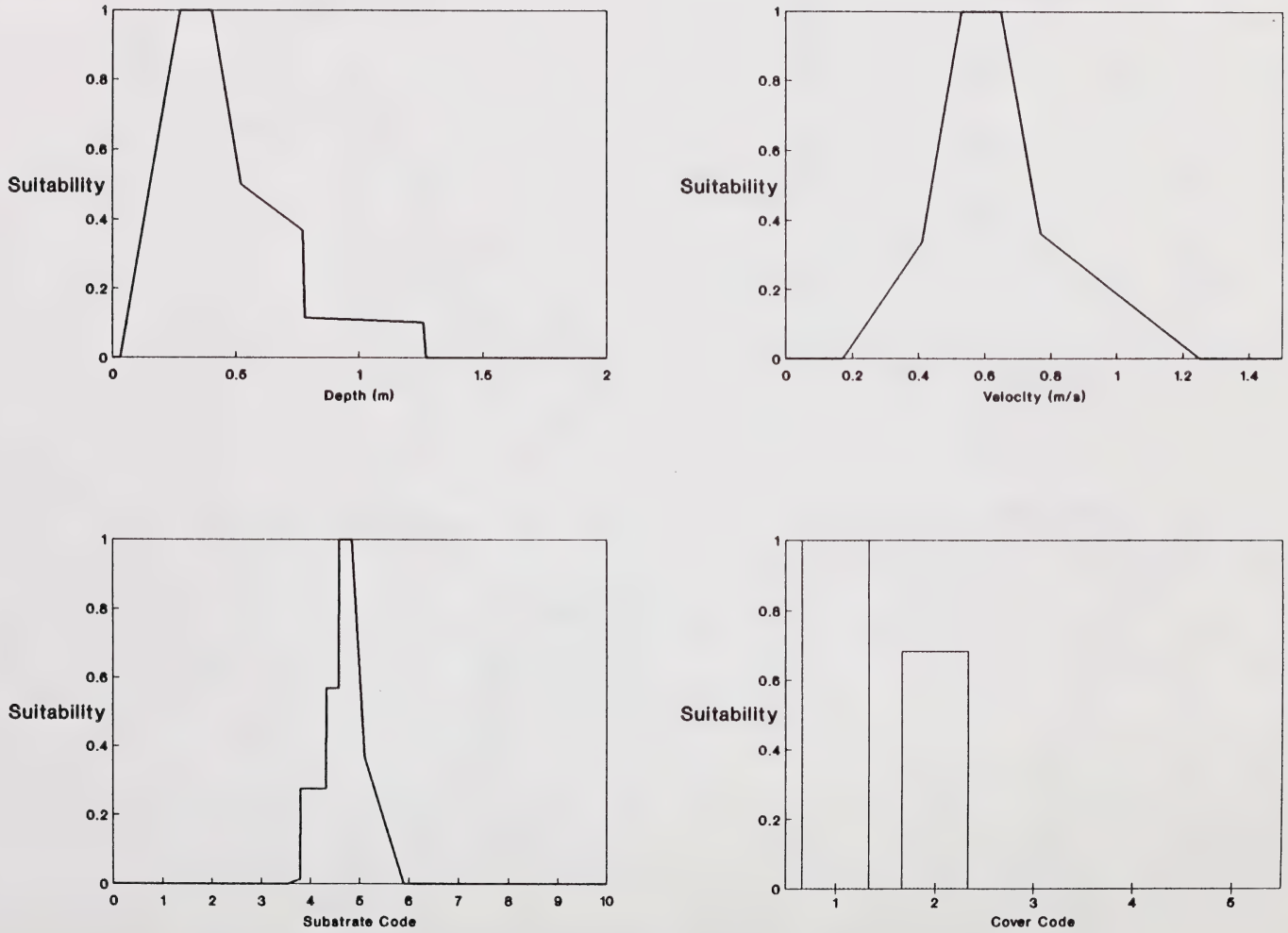



Figure 11. Brown trout spawning habitat preference curves.

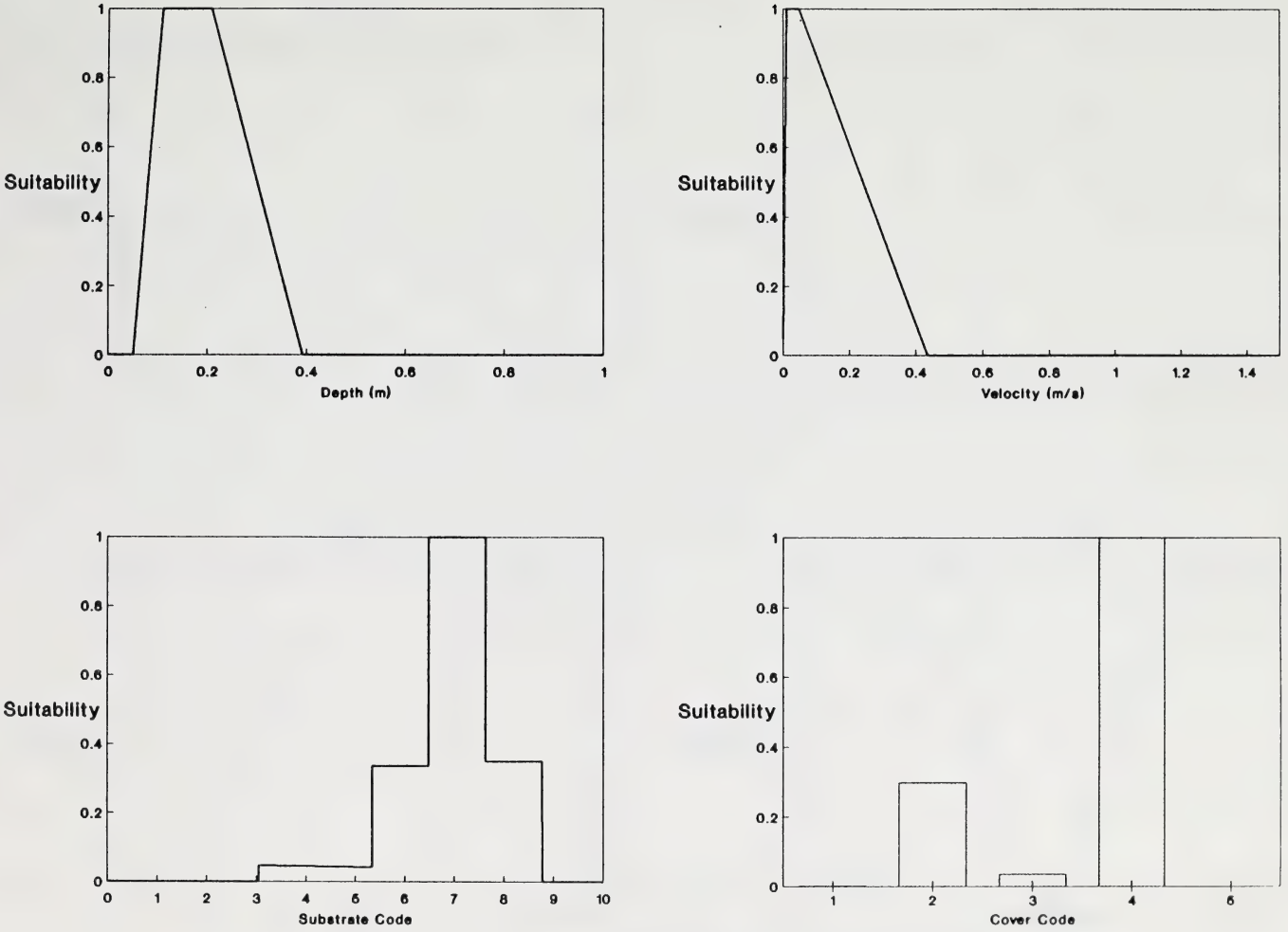



Figure 12. Rainbow trout fry habitat preference curves.

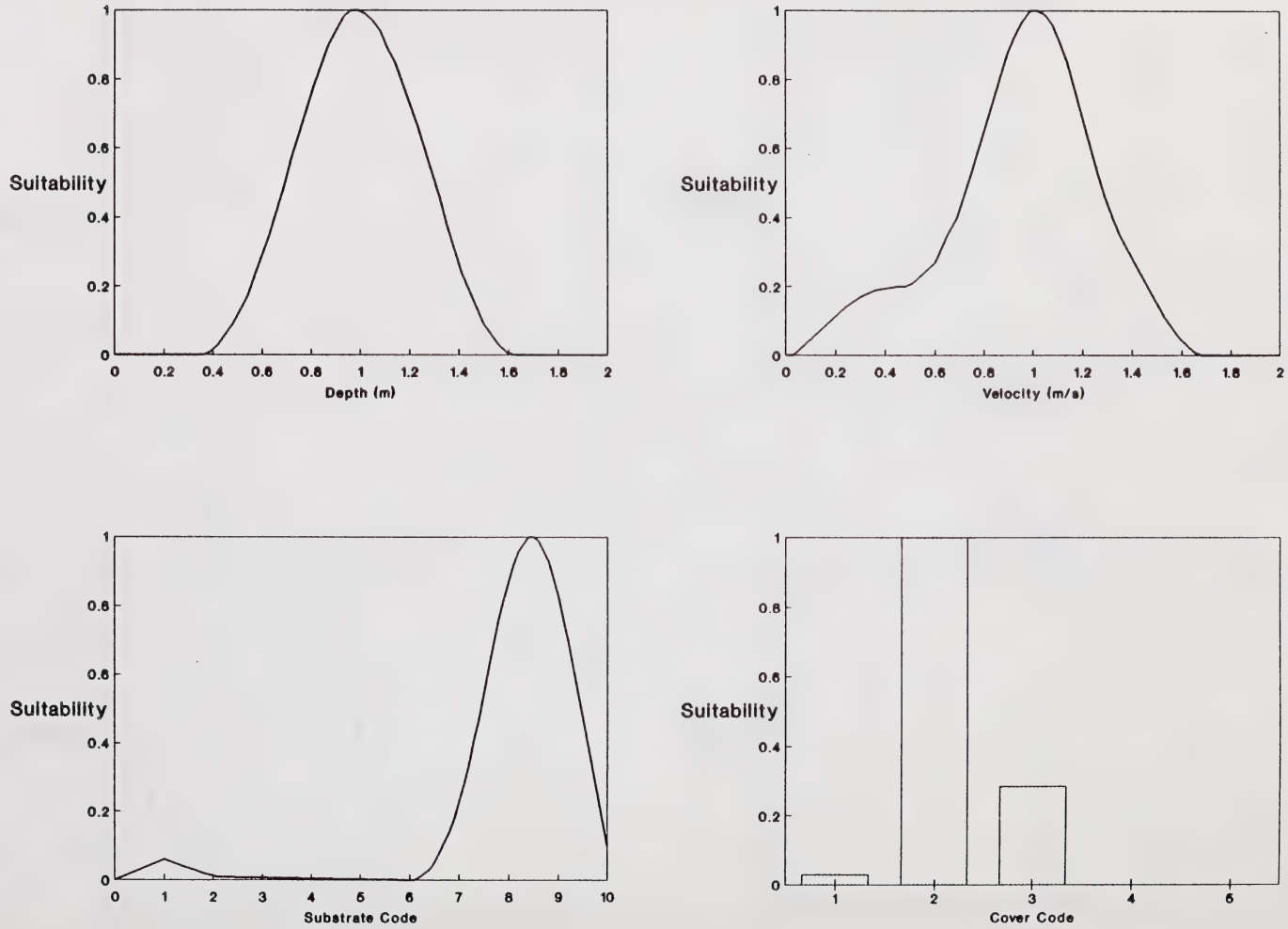
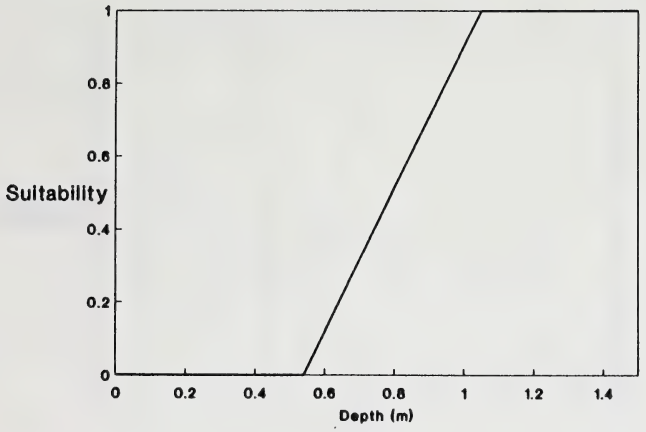
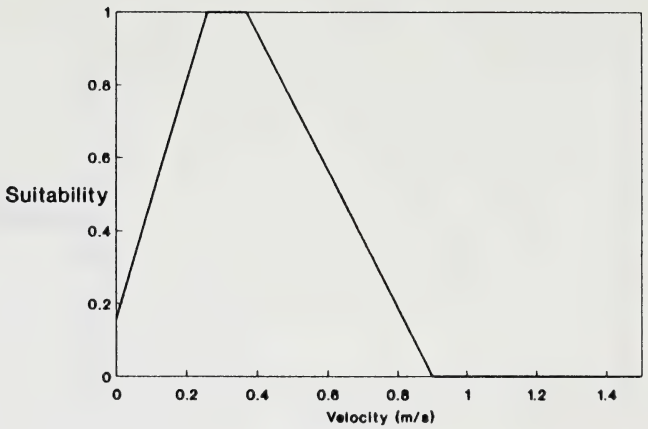
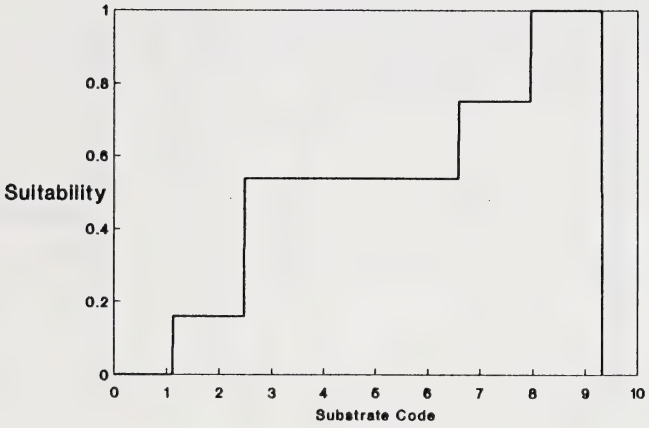



Figure 13. Rainbow trout juvenile habitat preference curves.



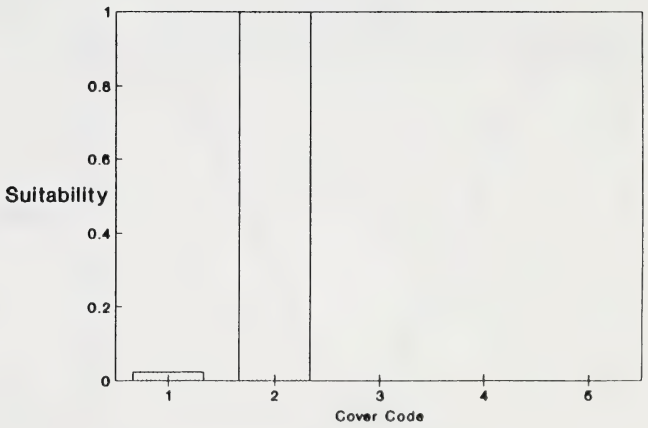




Figure 14. Rainbow trout adult habitat preference curves.

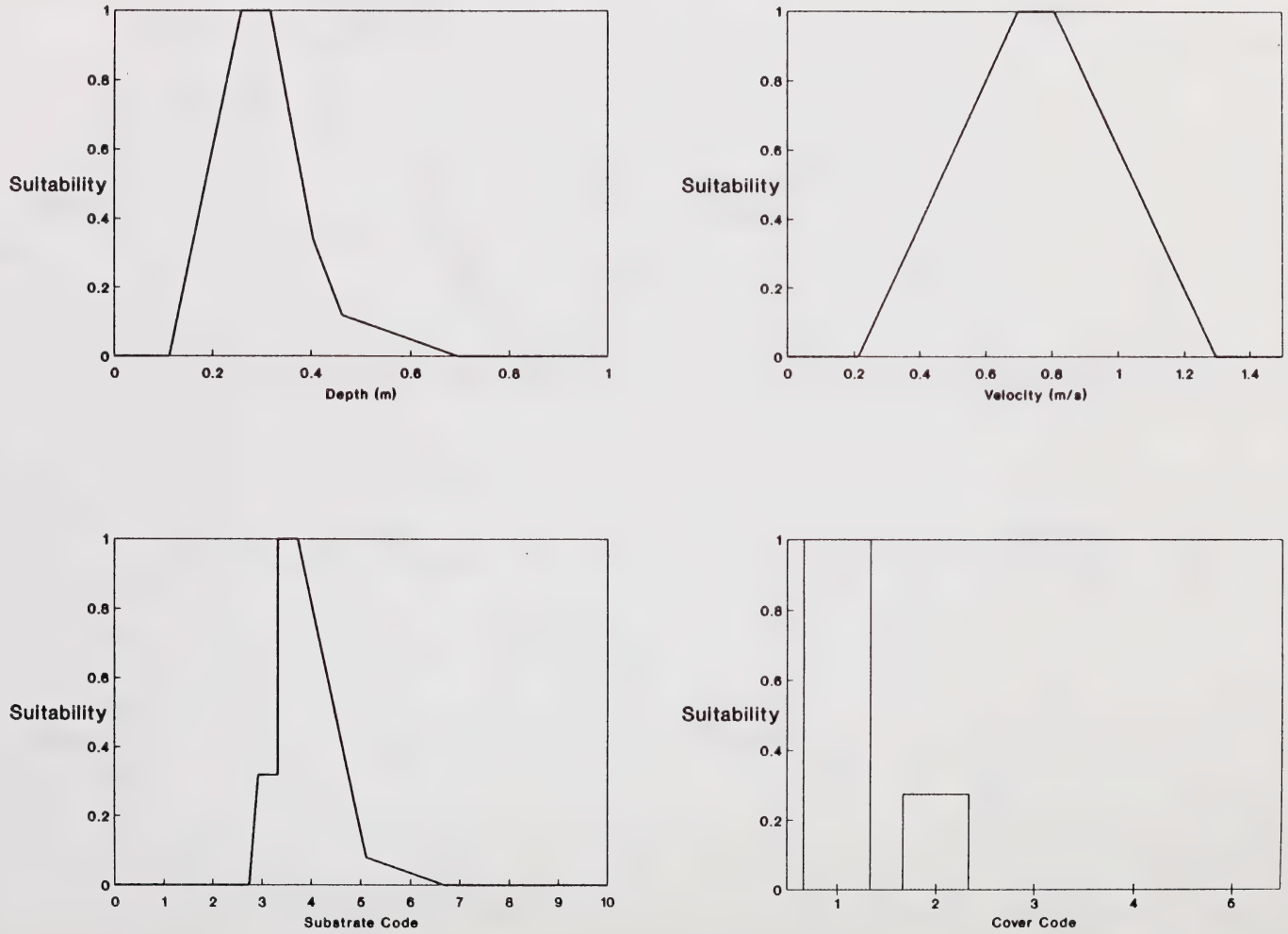
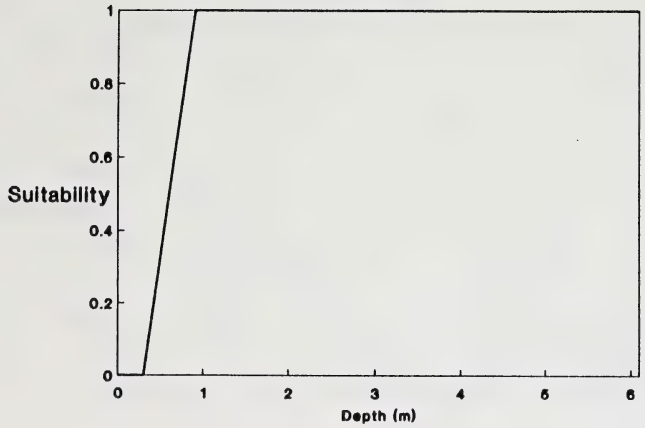
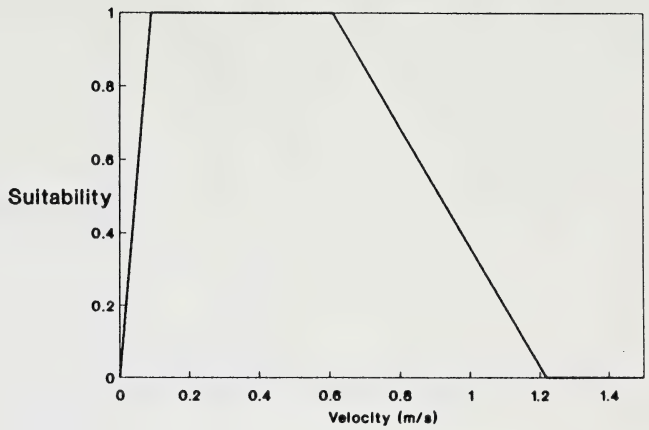



Figure 15. Rainbow trout spawning habitat preference curves.



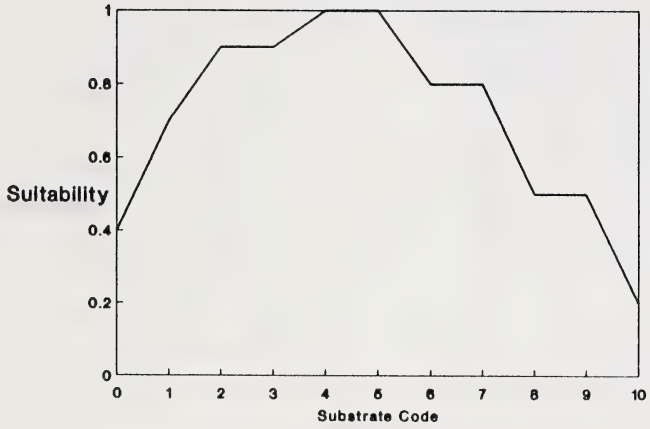




Figure 16. Sauger fry habitat preference curves.

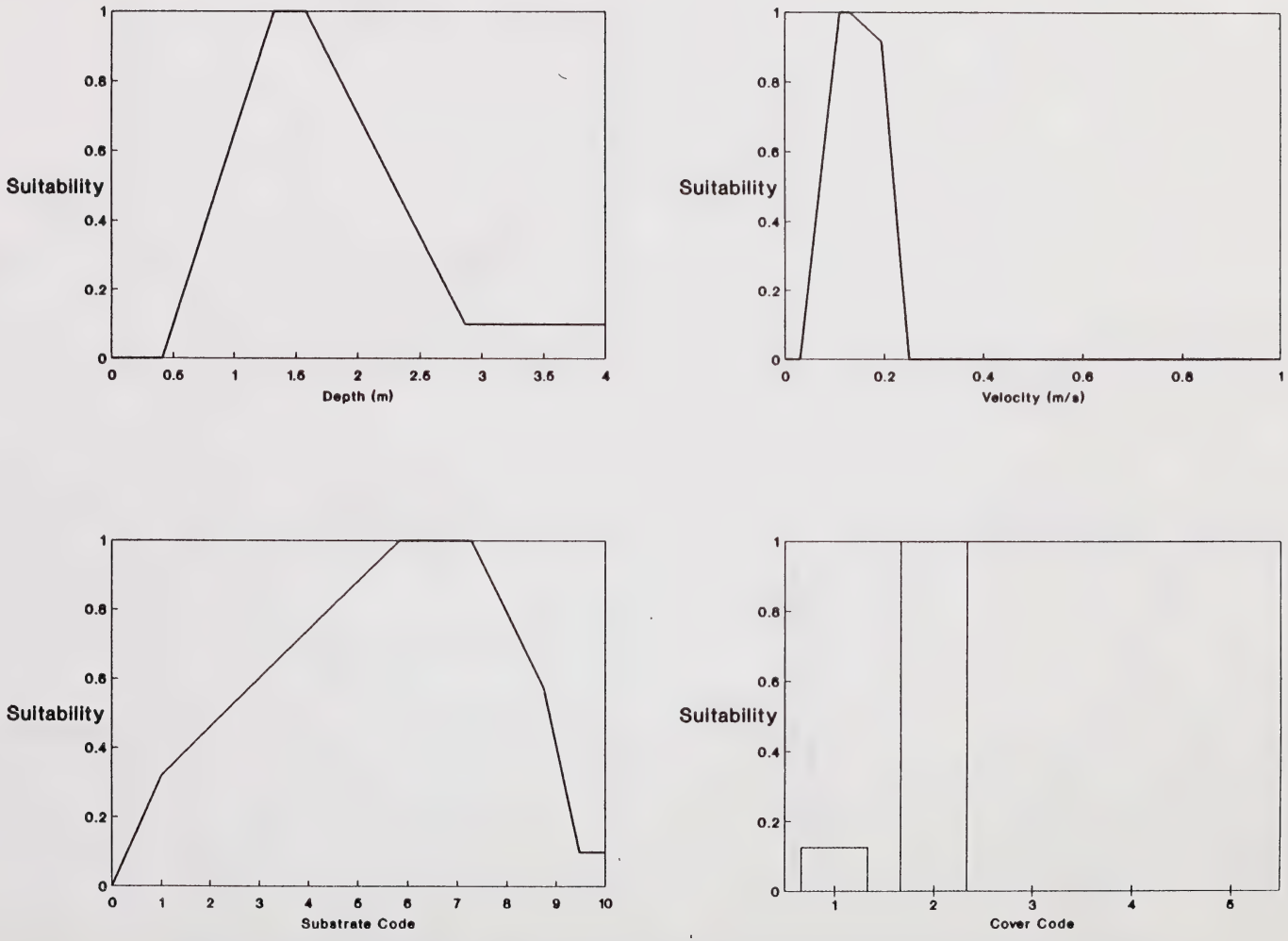



Figure 17. Sauger juvenile habitat preference curves.

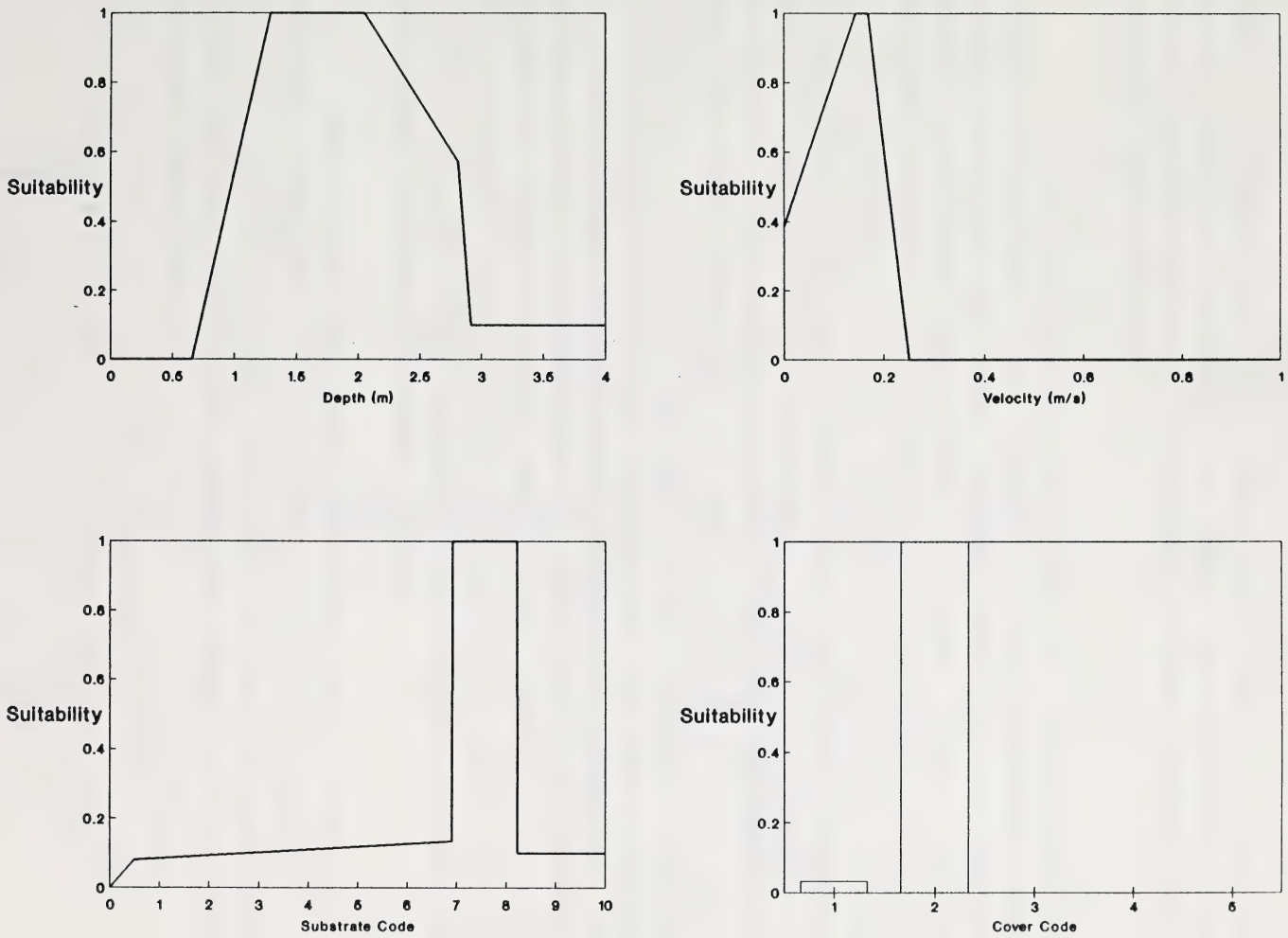



Figure 18. Sauger adult habitat preference curves.

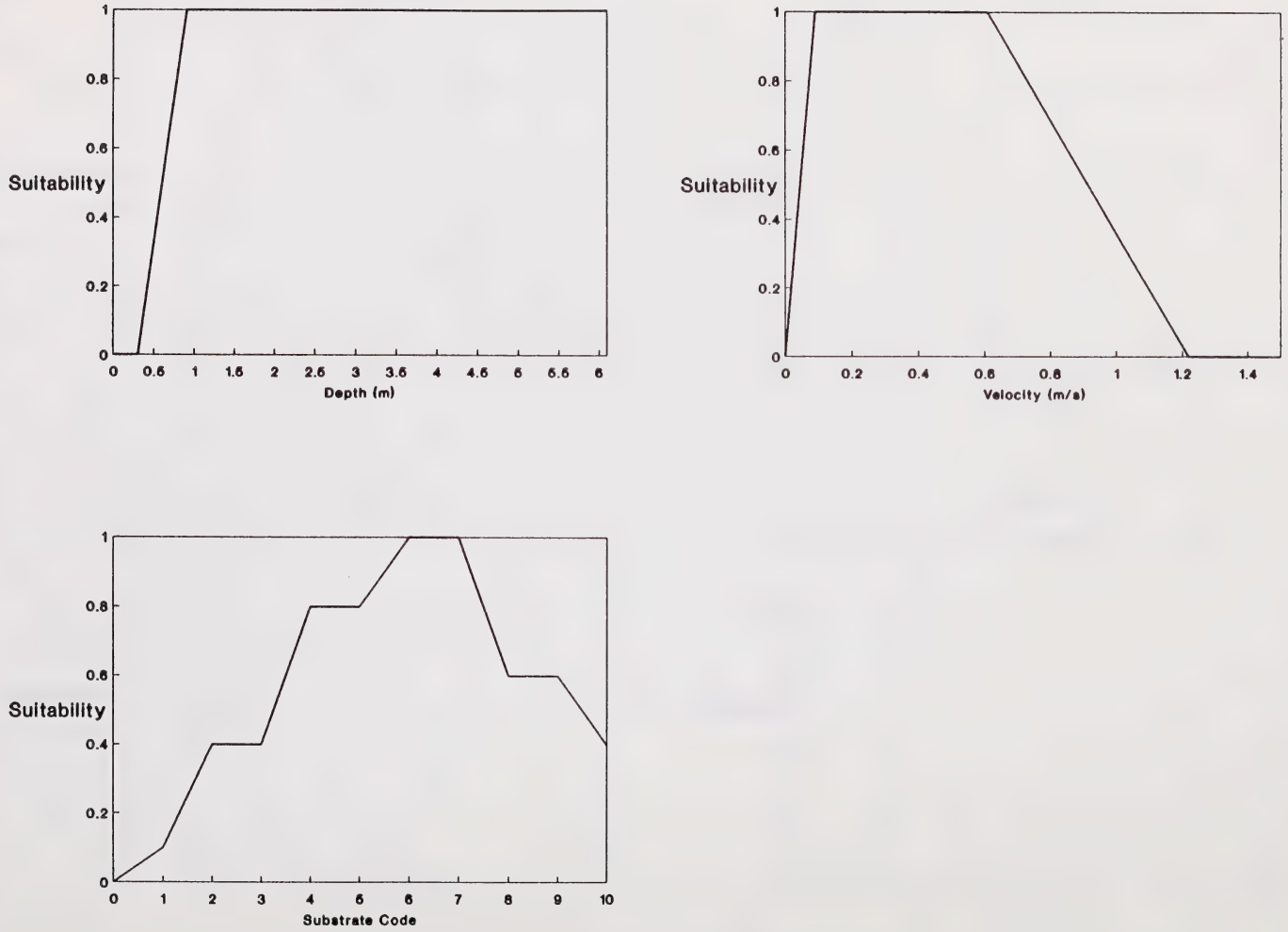
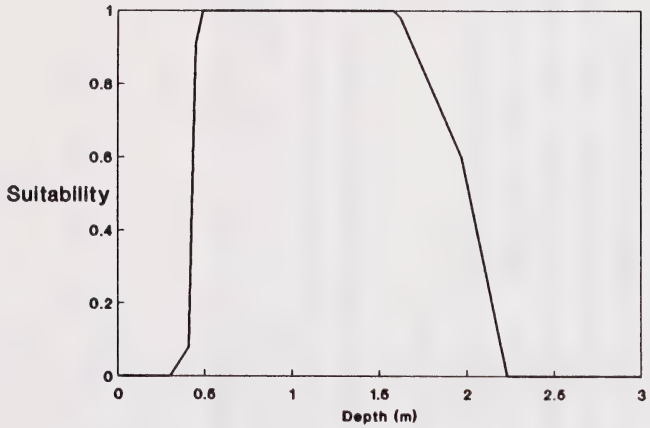


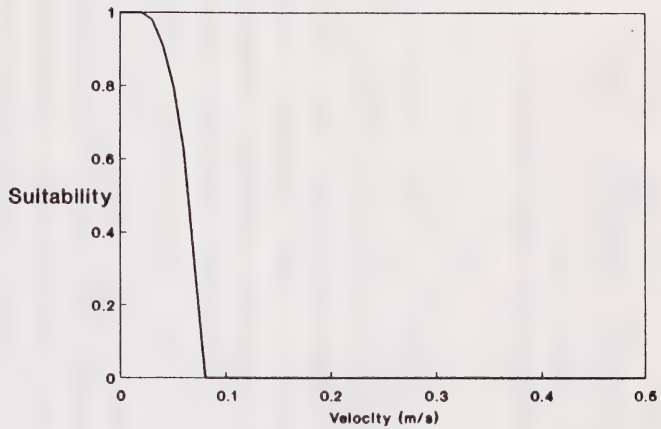

Figure 19. Sauger spawning habitat preference curves.

and therefore is not presented for the spawning and fry life stages. Although the cover preferences developed during the present study are presented for sauger (and walleye), these criteria were not employed in the analysis as these species are not considered cover dependent.

Diurnal differences were noted in the behaviour of walleye juveniles and adults. These life stages preferred deeper habitats during the day (likely holding behaviour) and shallower habitats with faster moving water at night (likely foraging behaviour). Therefore, the juvenile and adult habitat preferences are stratified by day and night. A comparable behaviour was noted for the sauger life stages present, but insufficient number of sauger were captured during the hours of darkness (adults n = 9, juveniles n = 15) to enable a meaningful analysis. The results of using this small sample size in the analysis are presented in Appendix IV, to illustrate the trend towards differential habitat preferences during the day and night periods. The walleye habitat preference criteria are summarized on Figures 20 through 25. As noted previously, the walleye spawning and fry habitat preferences employed were those reported by McMahon et al. (1984). As was the case with sauger, cover preferences were not available for the spawning and fry life stages, and substrate preference criteria had to be recoded as weighted average indices.

The data sets utilized in the development of the habitat preferences identified in this study are presented in Appendix IV. These data sets involve the distribution of available habitats, habitats which were used by the target life stage, and the habitat preferences identified.



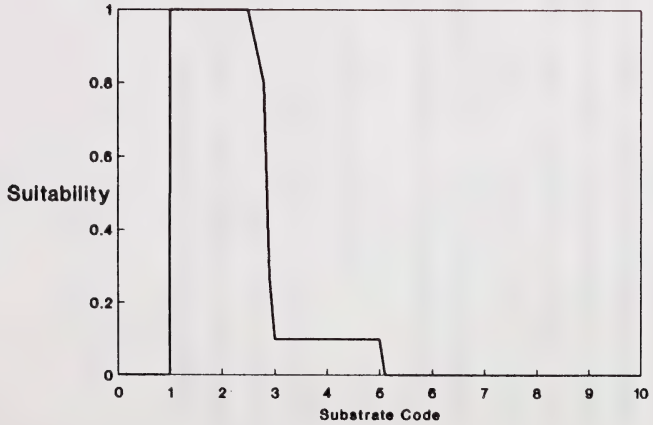




Figure 20. Walleye fry habitat preference curves.

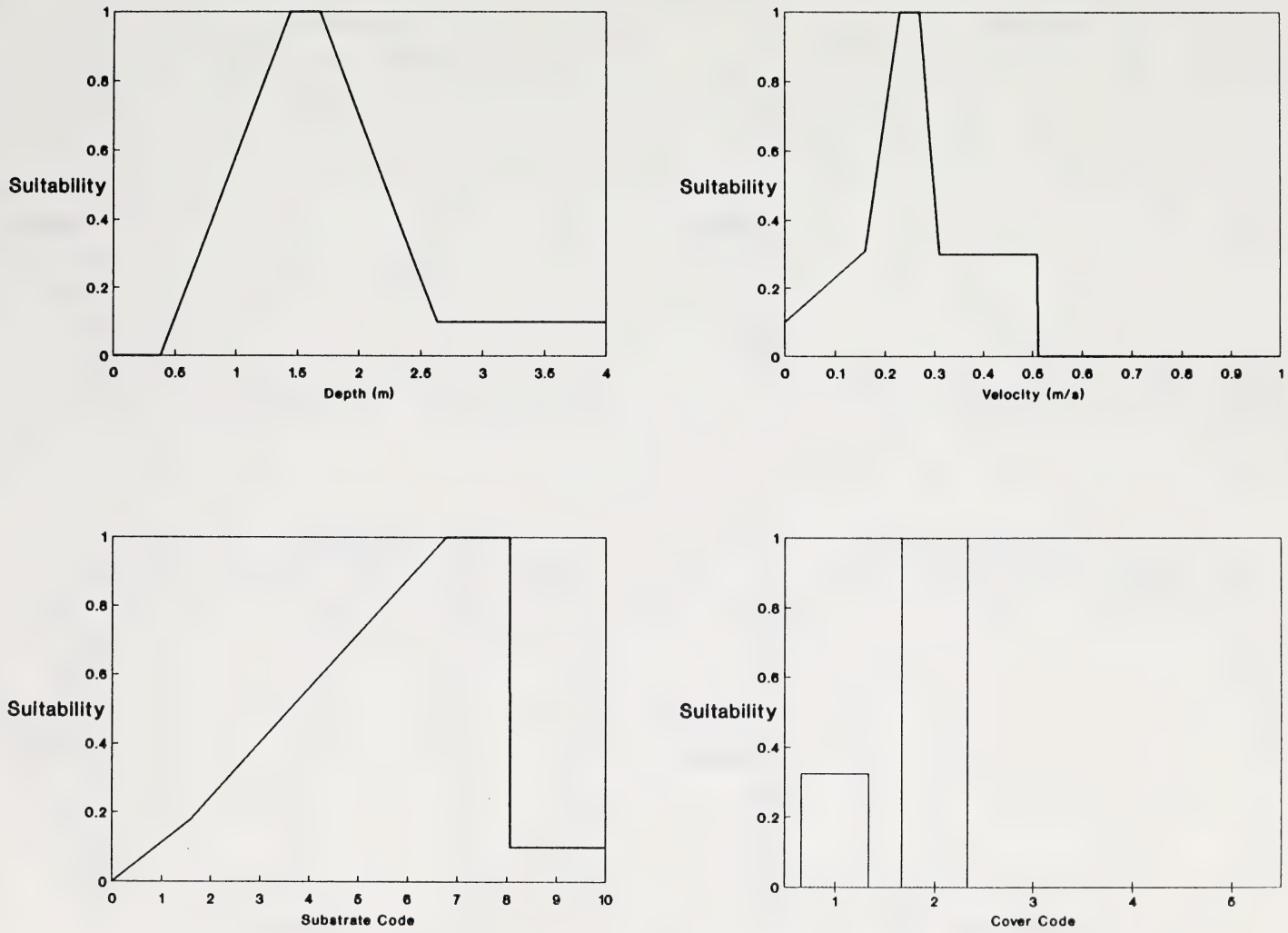
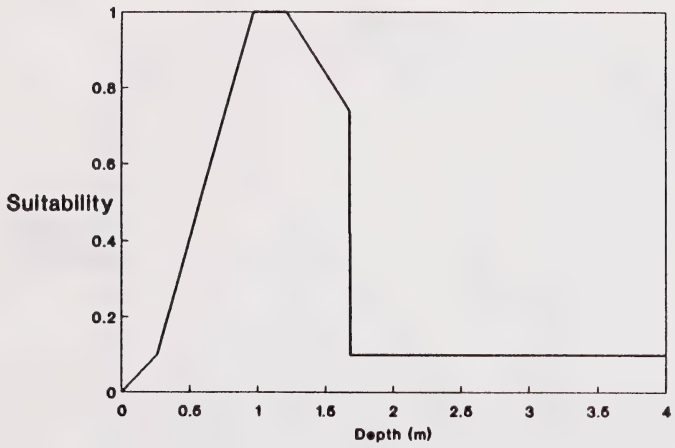
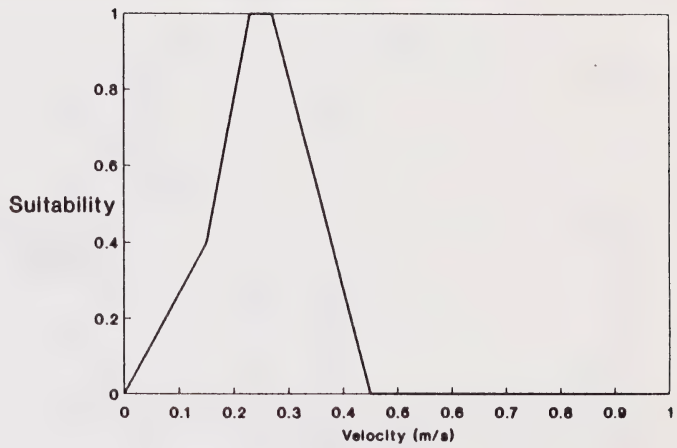
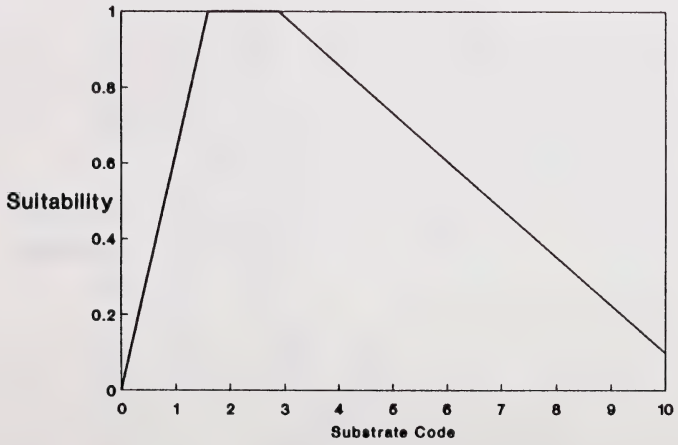



Figure 21. Walleye juvenile (day) habitat preference curves.



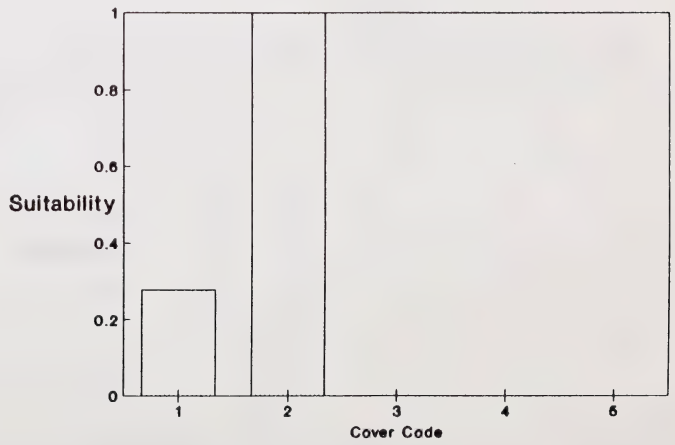




Fig. 22. Walleye juvenile (night) habitat preference curves.

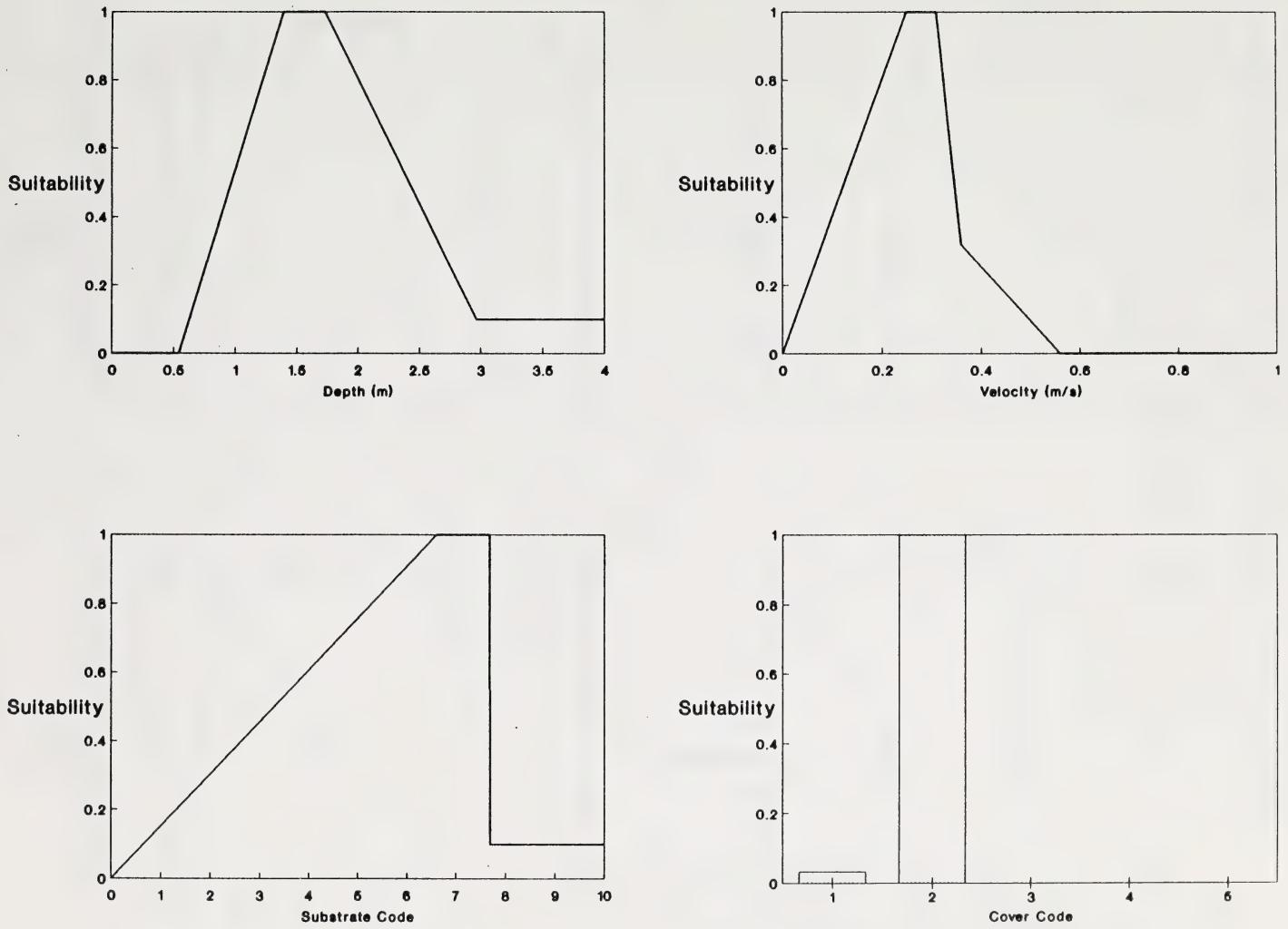



Figure 23. Walleye adult (day) habitat preference curves.

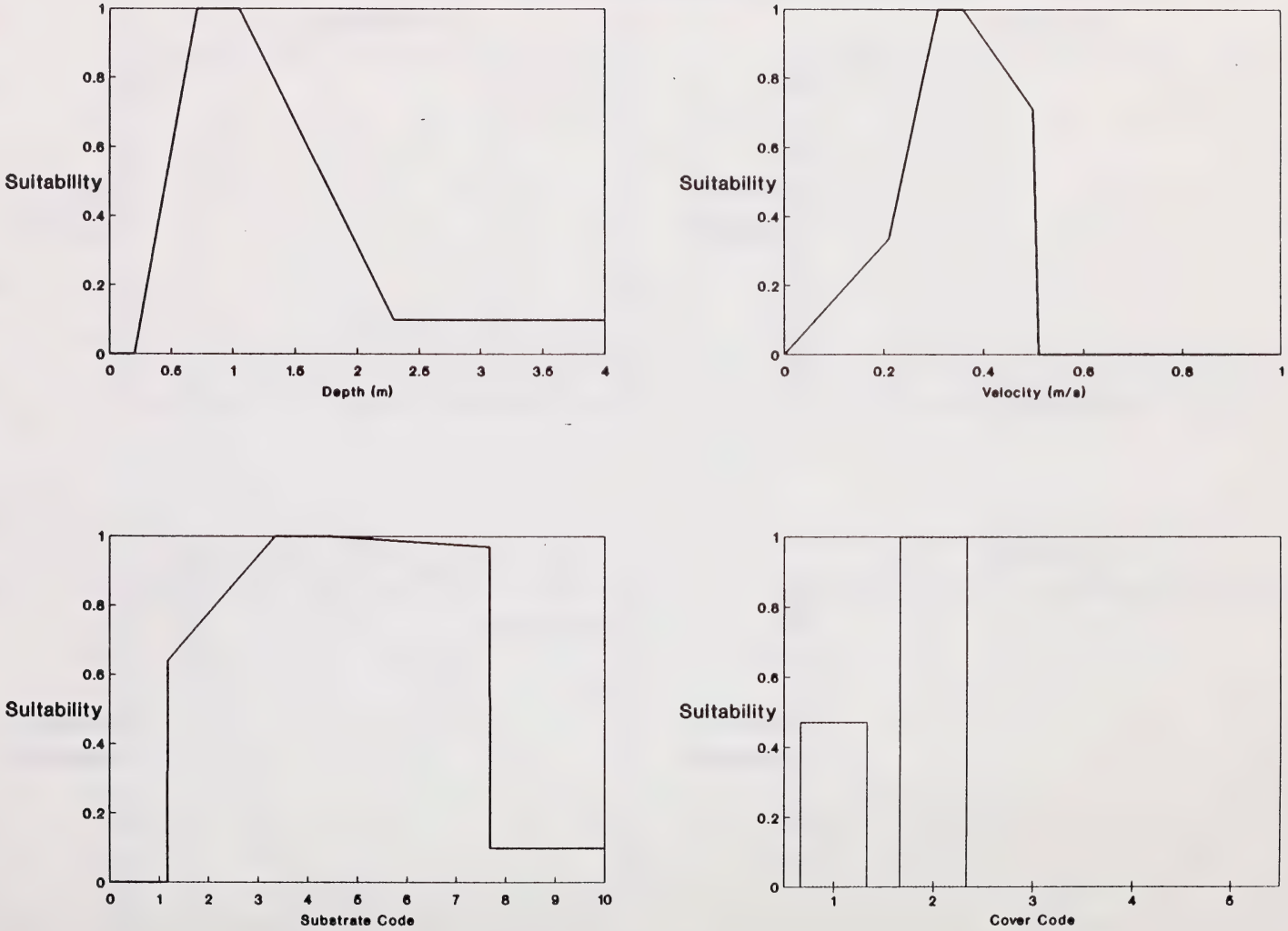
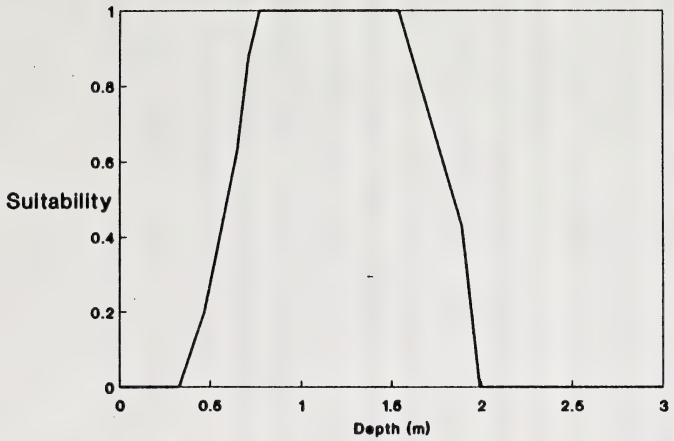
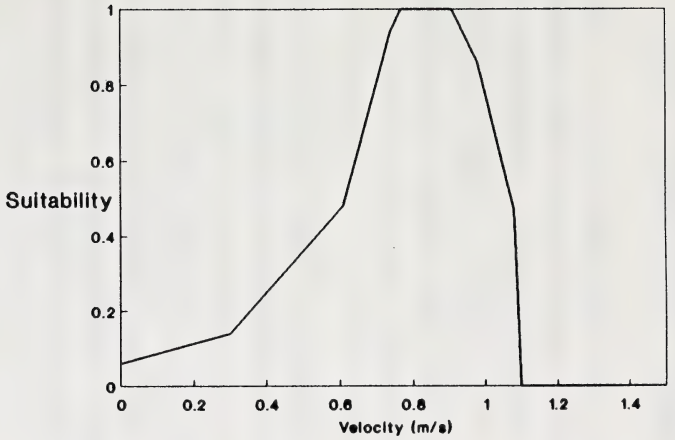



Figure 24. Walleye adult (night) habitat preference curves.



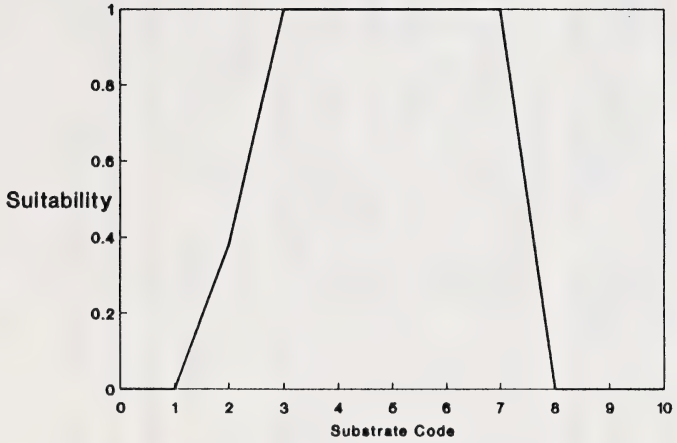




Figure 25. Walleye spawning habitat preference curves.

### 6.2.2 Transferability of Habitat Preference Curves

The results of evaluating the applicability of the walleye and sauger habitat preferences to the Oldman River Study Area were inconclusive, as no walleye or sauger were encountered in Study Reaches 1 and 2 (Section 5.2.6). However, as the juvenile and adult preferences were generated from the Oldman River, the transferability of this information is not an issue.

The applicability of the spawning and fry habitat preferences for walleye and sauger to the Oldman River may not be evaluated, as these life stages were not encountered in the Oldman River in 1988. However, the walleye spawning preferences did conform with information collected in the Puskwakau River in Saskatchewan in 1988 (Dr. W. Liaw, Saskatchewan Fisheries Laboratory, pers. comm.), which illustrated some degree of transferability for these criteria.

The brown trout habitat preference criteria developed during the study have been judged as being suitable for use in the Oldman River, although the transferability analysis was not conclusive (See Appendix I). Some difficulties were encountered with the habitat preferences identified for the rainbow trout fry and adult life stages in the Crowsnest River, which have been attributed to the low flow conditions and narrow range of available habitats experienced in 1988. The preferences which were identified are likely too narrow (i.e., the fry and adults would likely use a wider range of habitat characteristics than those which are identified). However, as the Crowsnest is tributary to the Oldman River, and the rainbow trout population downstream of Lundbreck Falls is likely the same one found in the Oldman River, the criteria which are identified would be applicable to the Oldman River (See Appendix I).

## 6.3 HABITAT AVAILABILITY AS A FUNCTION OF STREAMFLOW

The calculation of habitat availability (WUA) as a function of discharge is facilitated with the use of the IFG4 and HABTAT models. The IFG4 model simulates the physical and hydraulic characteristics of the river at the specified discharge. The HABTAT model compares these calculated physical and hydraulic characteristics with the habitat preference criteria for the target life stages to calculate habitat availability (WUA). Through a series of computer simulations over a range of flows, the relationship between WUA and discharge may be compiled.

The physical and hydraulic characteristics of each river segment are different, which results in differences in the WUA versus flow relationship for each segment. The relationships between habitat availability (excluding cover considerations) and flow for the rainbow trout life stages for the coldwater river segments, and brown trout for all six segments are illustrated in Figures 26 through 34. As previously noted, if cover was included as a variable in these analyses, there would be essentially no habitat for either species within the flow range examined.

The WUA versus flow relationships for walleye and sauger in the Oldman River, based on depth, velocity and substrate criteria are presented on Figures 35 through 40 for the coolwater region of the Study Area. Although cover preferences were developed for walleye and sauger, these species are not typically considered to be cover-dependent. Cover was therefore not included as a variable in the model.

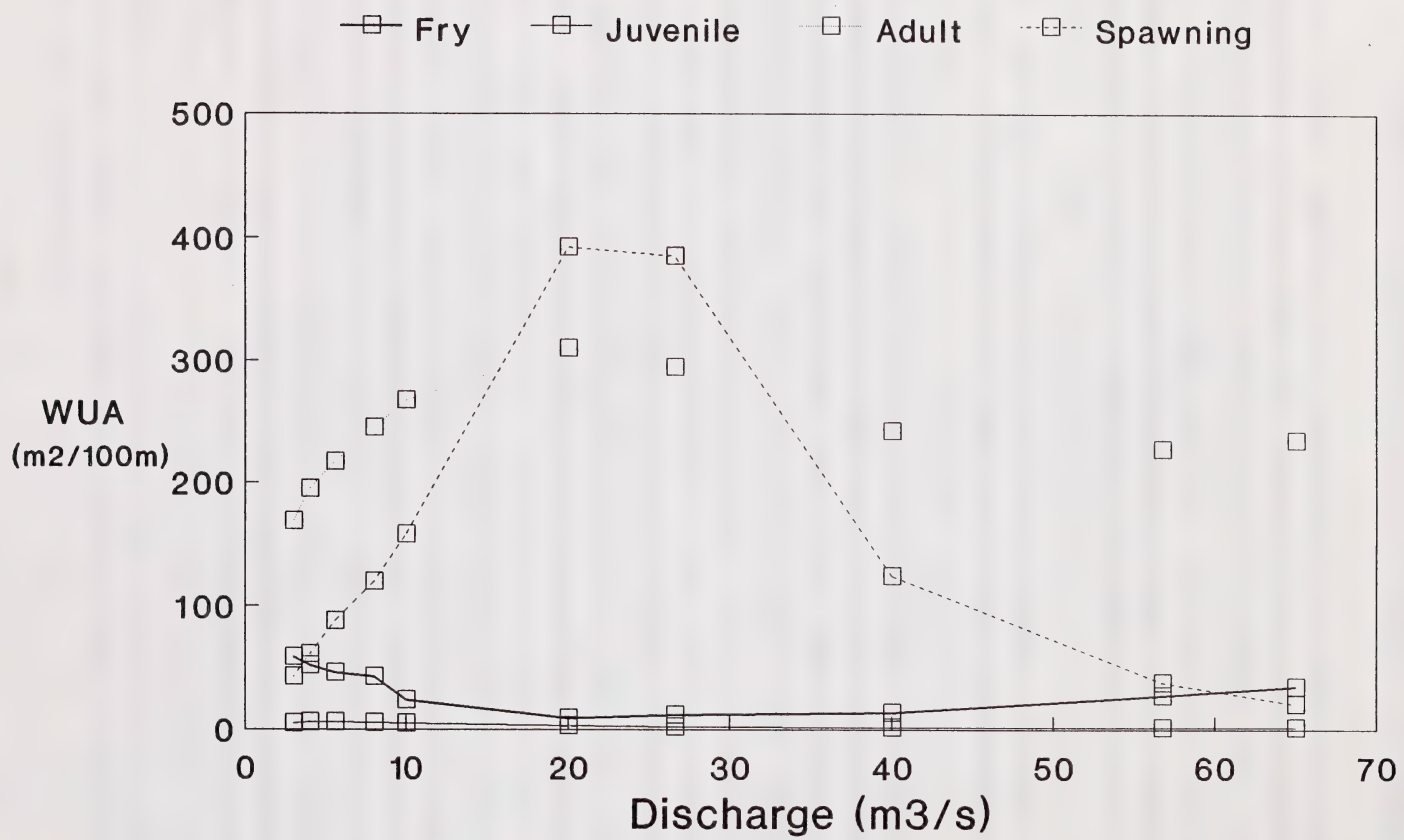



Figure 26. Rainbow trout weighted usable area versus discharge for segment 4.

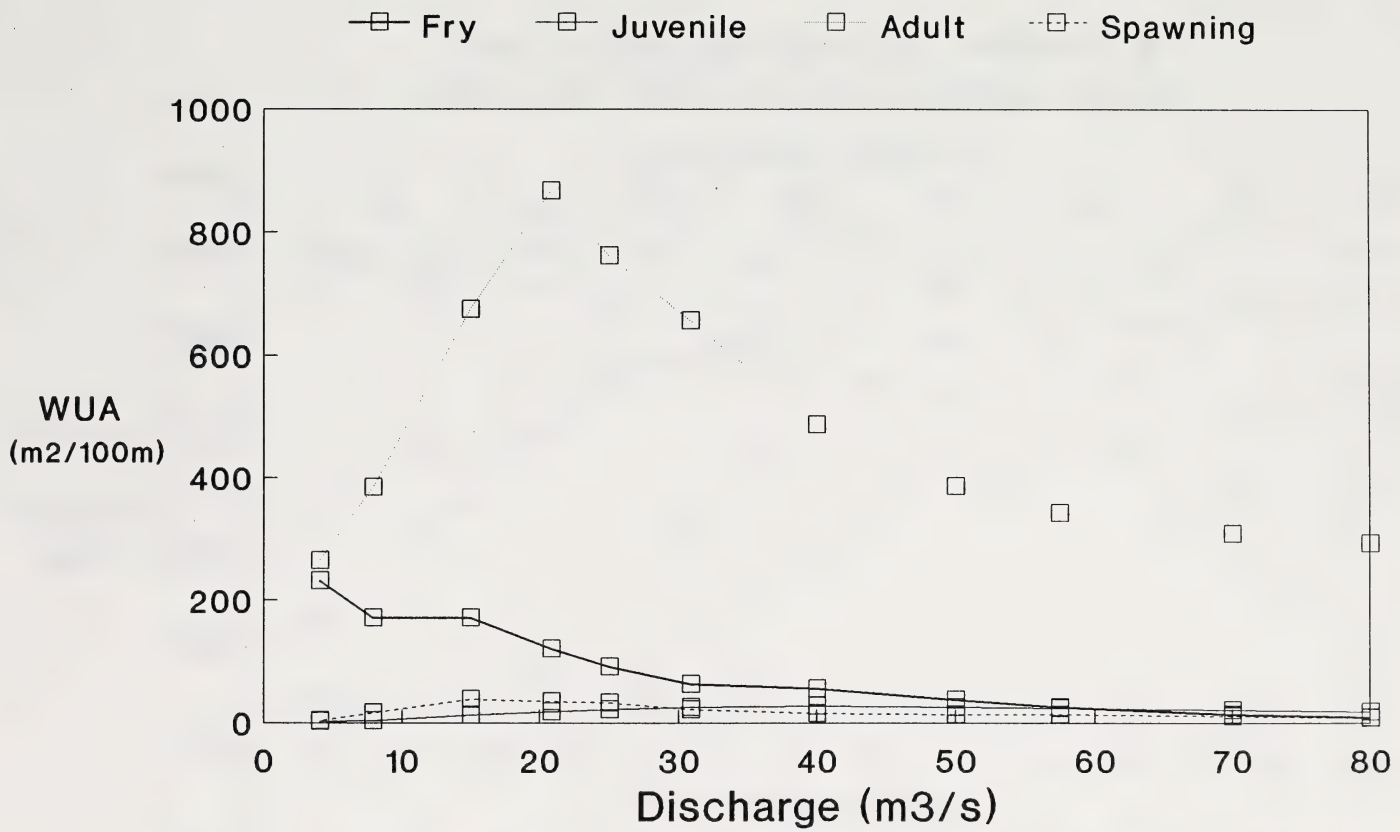



Figure 27. Rainbow trout weighted usable area versus discharge for segment 5.

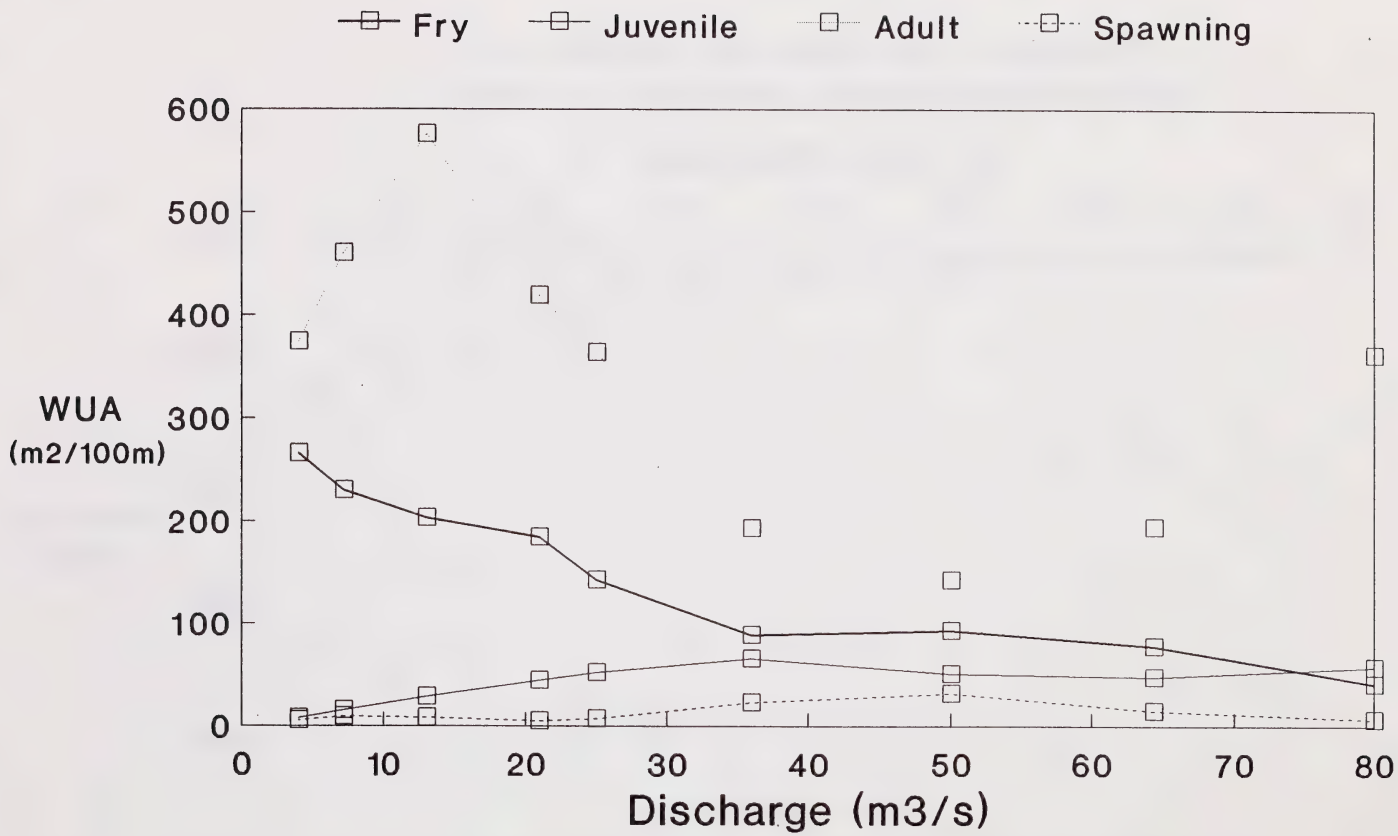



Figure 28. Rainbow trout weighted usable area versus discharge for segment 6.

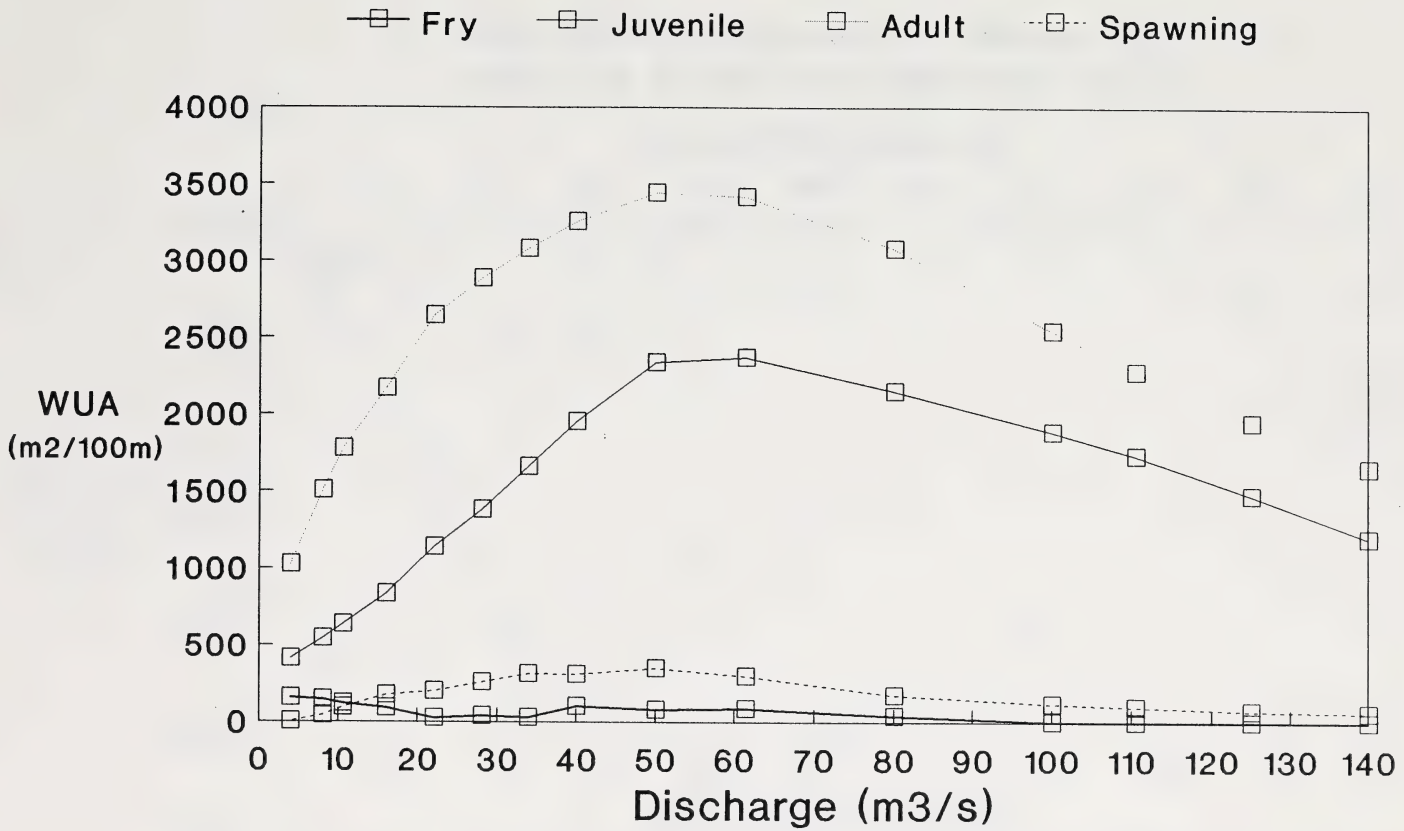



Figure 29. Brown trout weighted usable area versus discharge for segment 1.

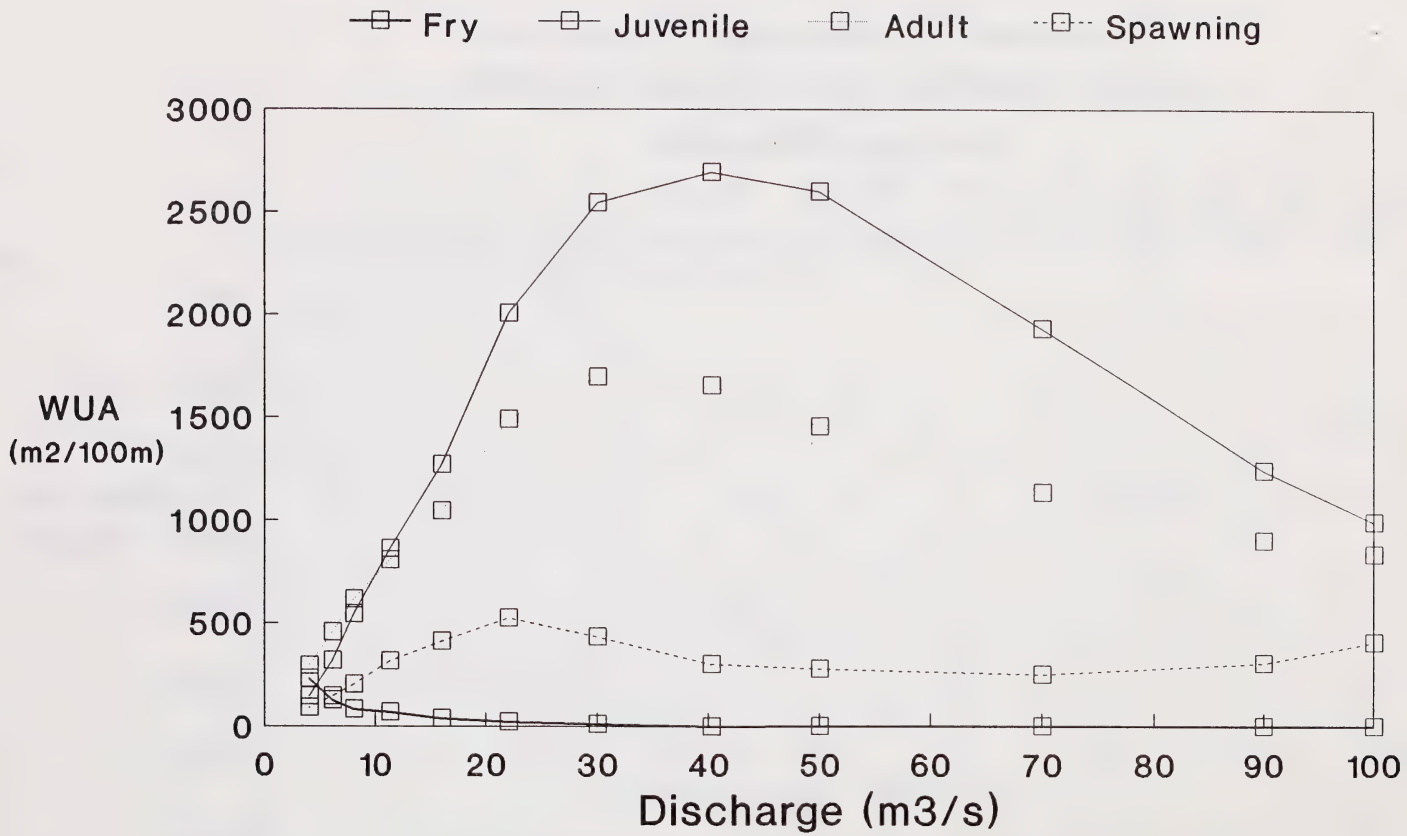



Figure 30. Brown trout weighted usable area versus discharge for segment 2.

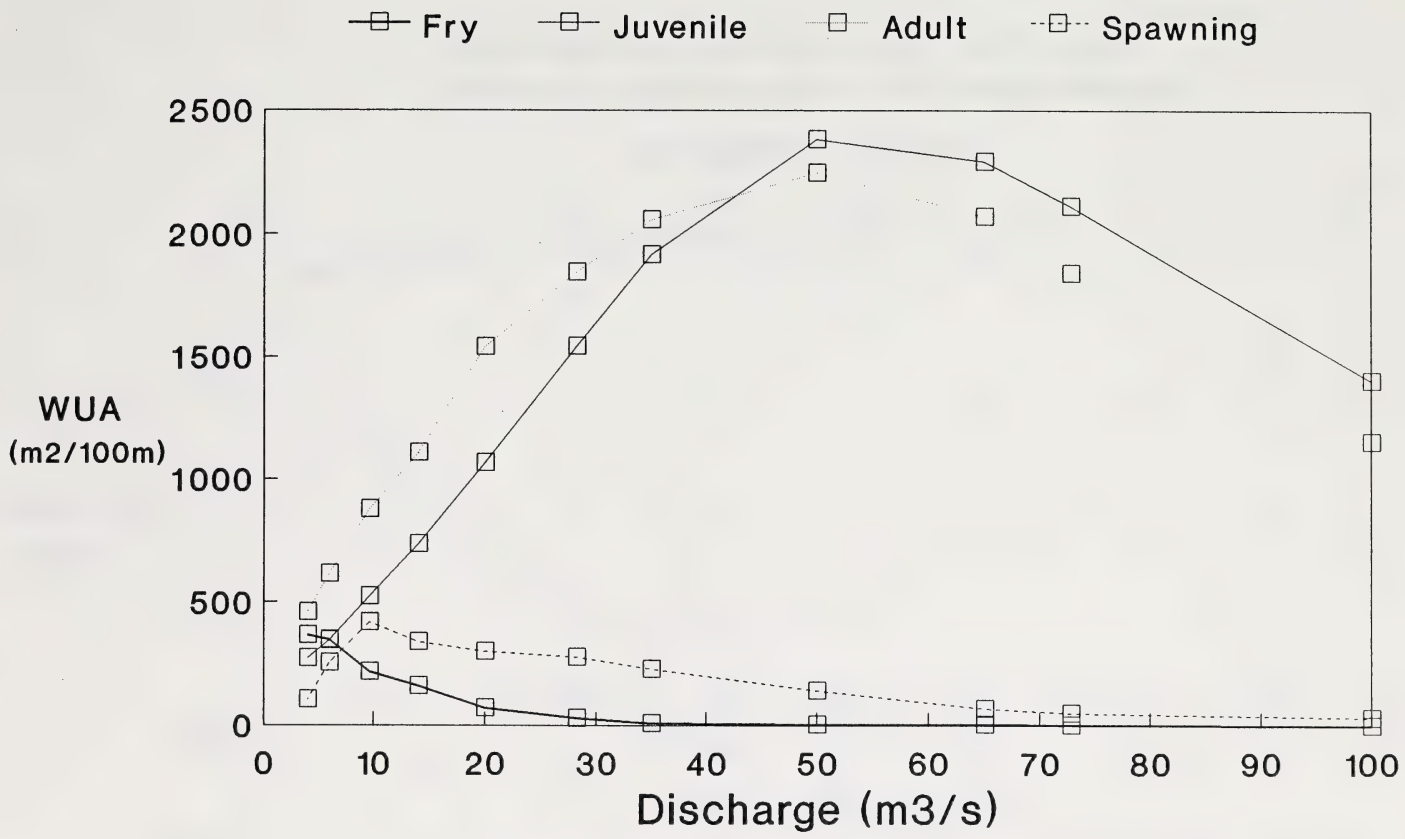



Figure 31. Brown trout weighted usable area versus discharge for segment 3.

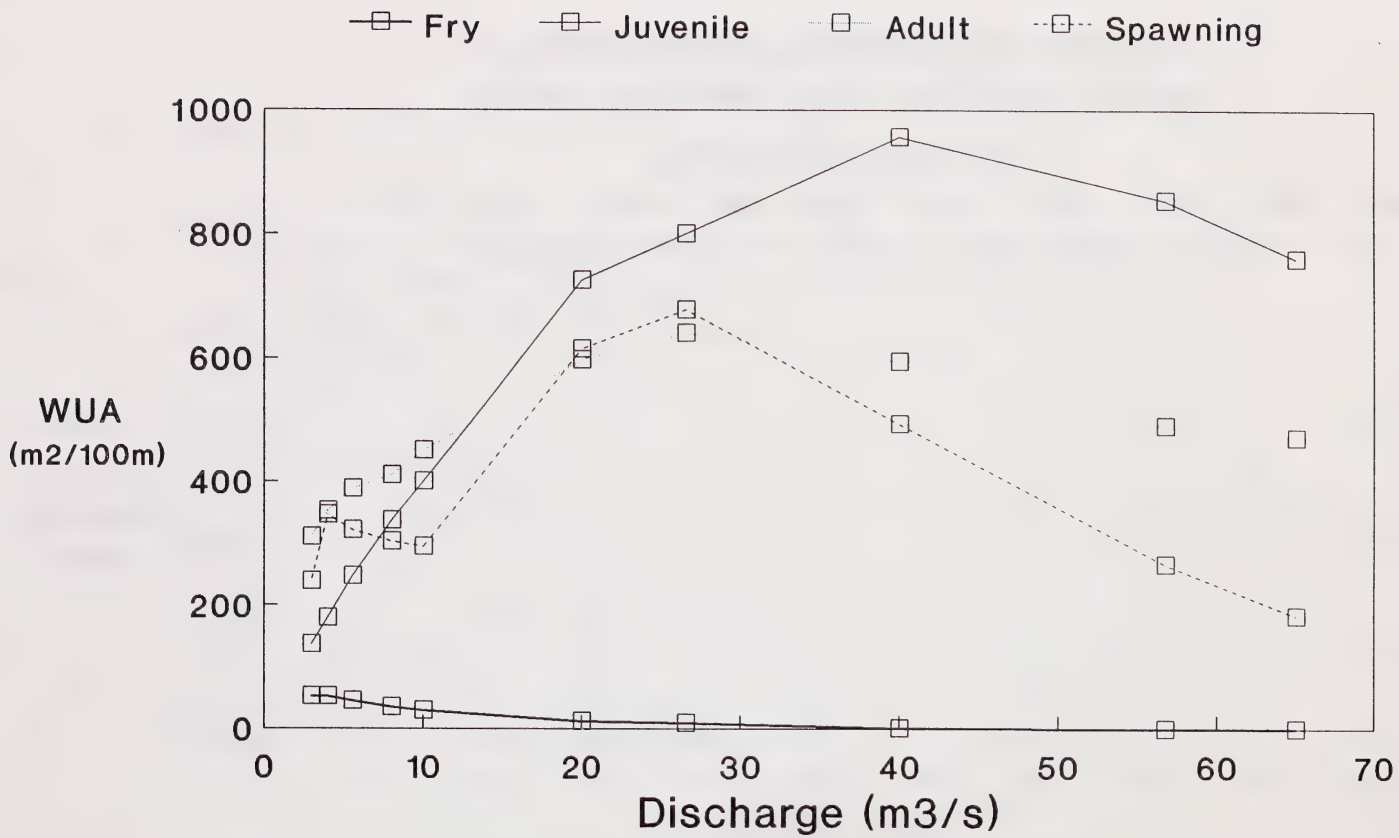



Figure 32. Brown trout weighted usable area versus discharge for segment 4.

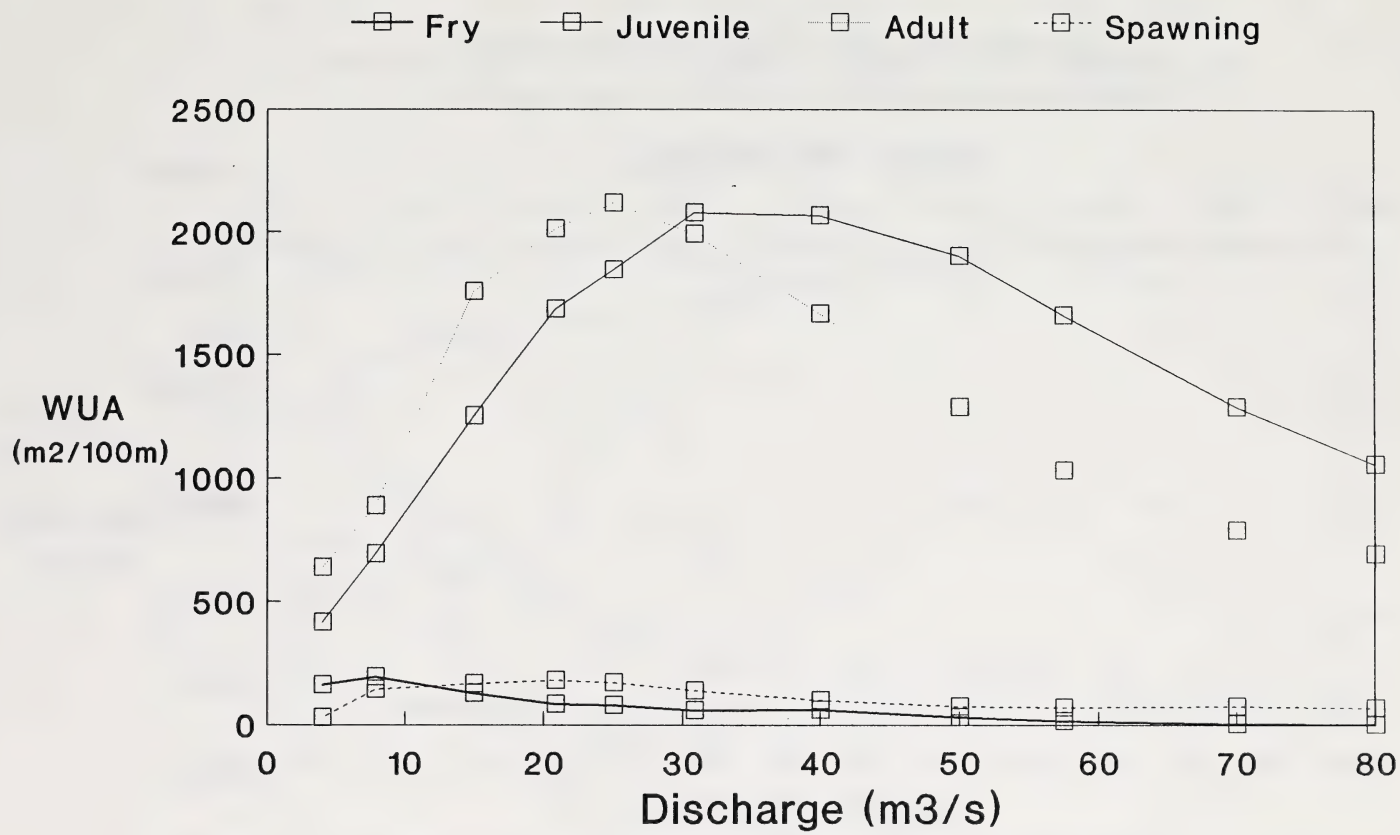



Figure 33. Brown trout weighted usable area versus discharge for segment 5.

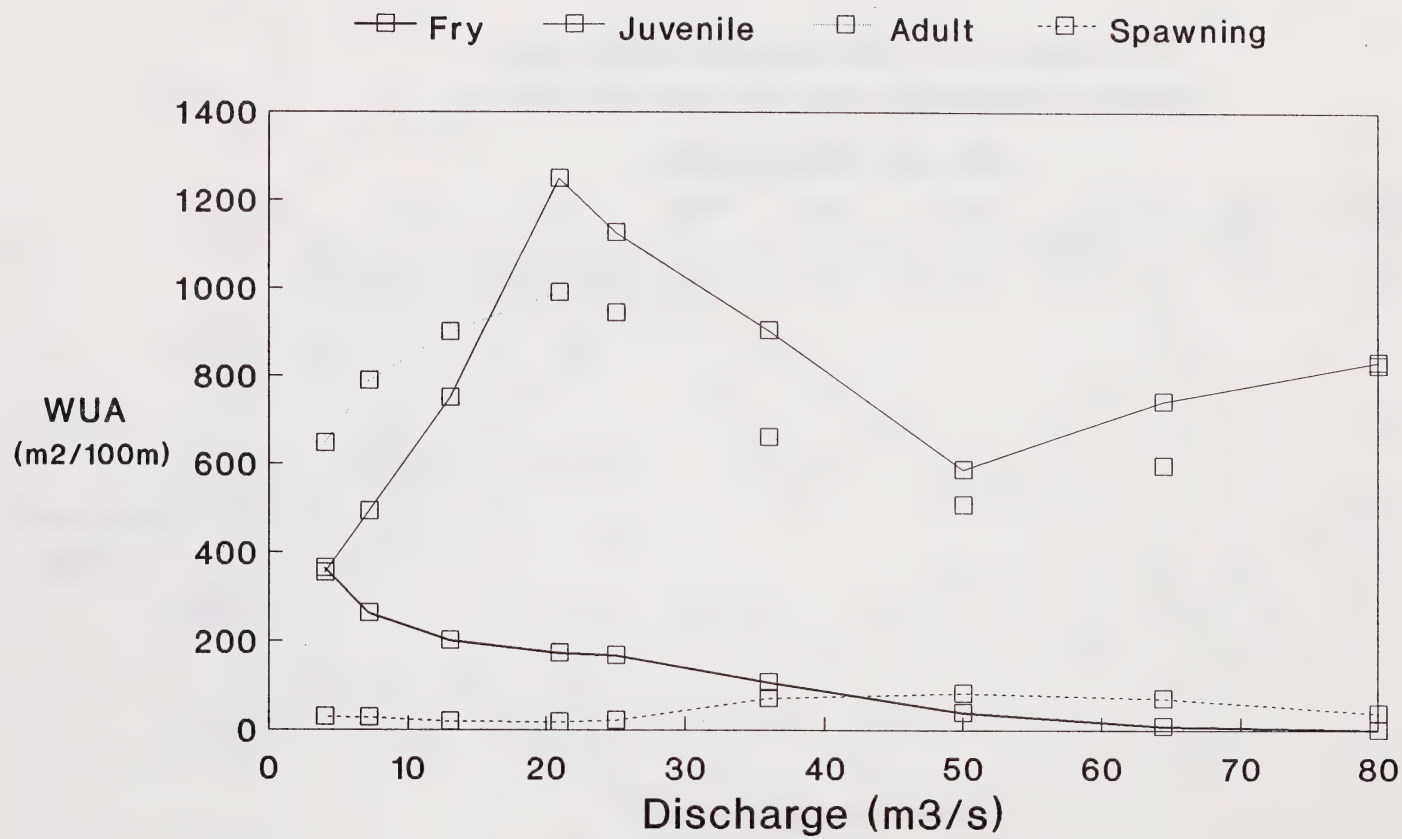



Figure 34. Brown trout weighted usable area versus discharge for segment 6.

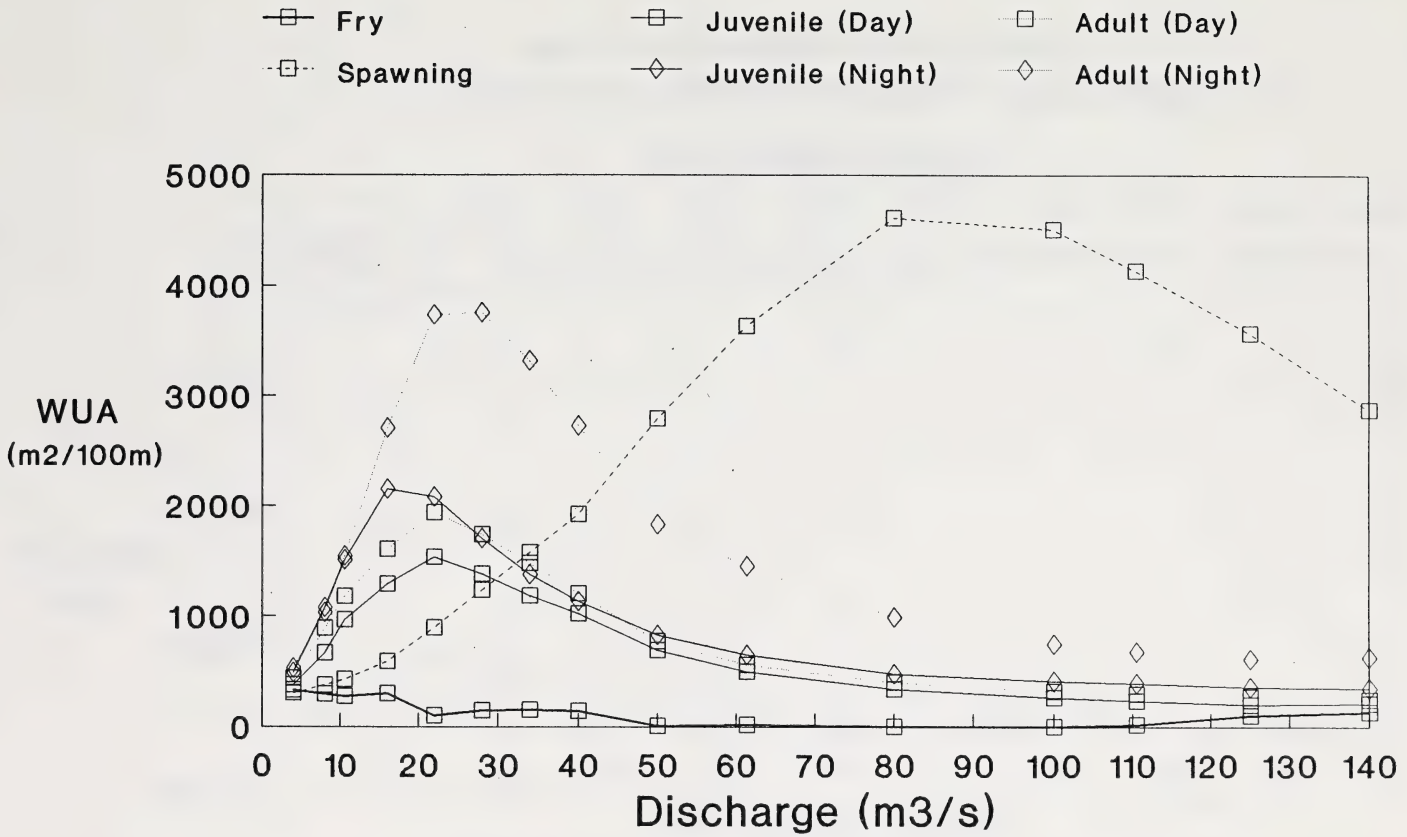



Figure 35. Walleye weighted usable area versus discharge for segment 1.

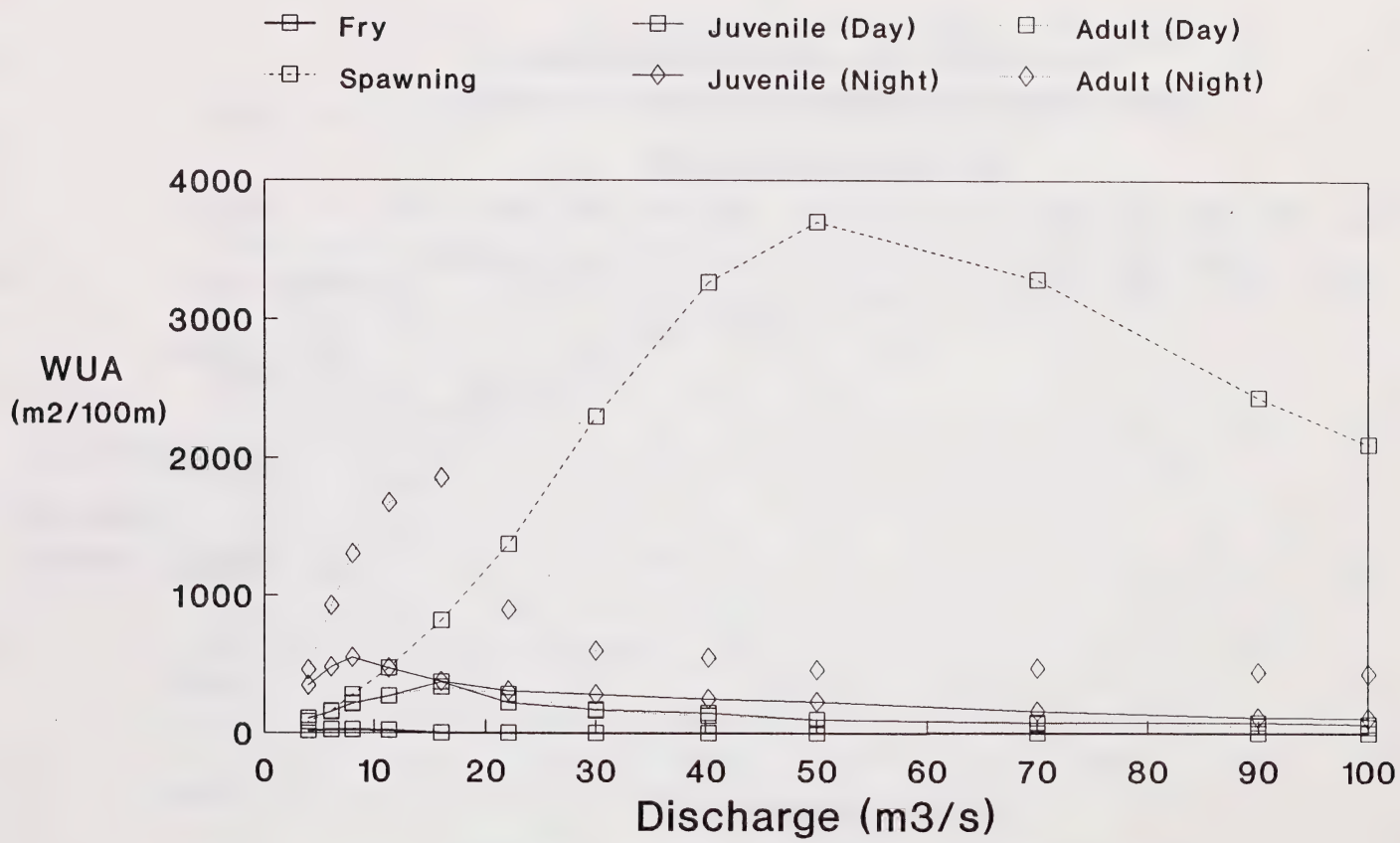



Figure 36. Walleye weighted usable area versus discharge for segment 2.

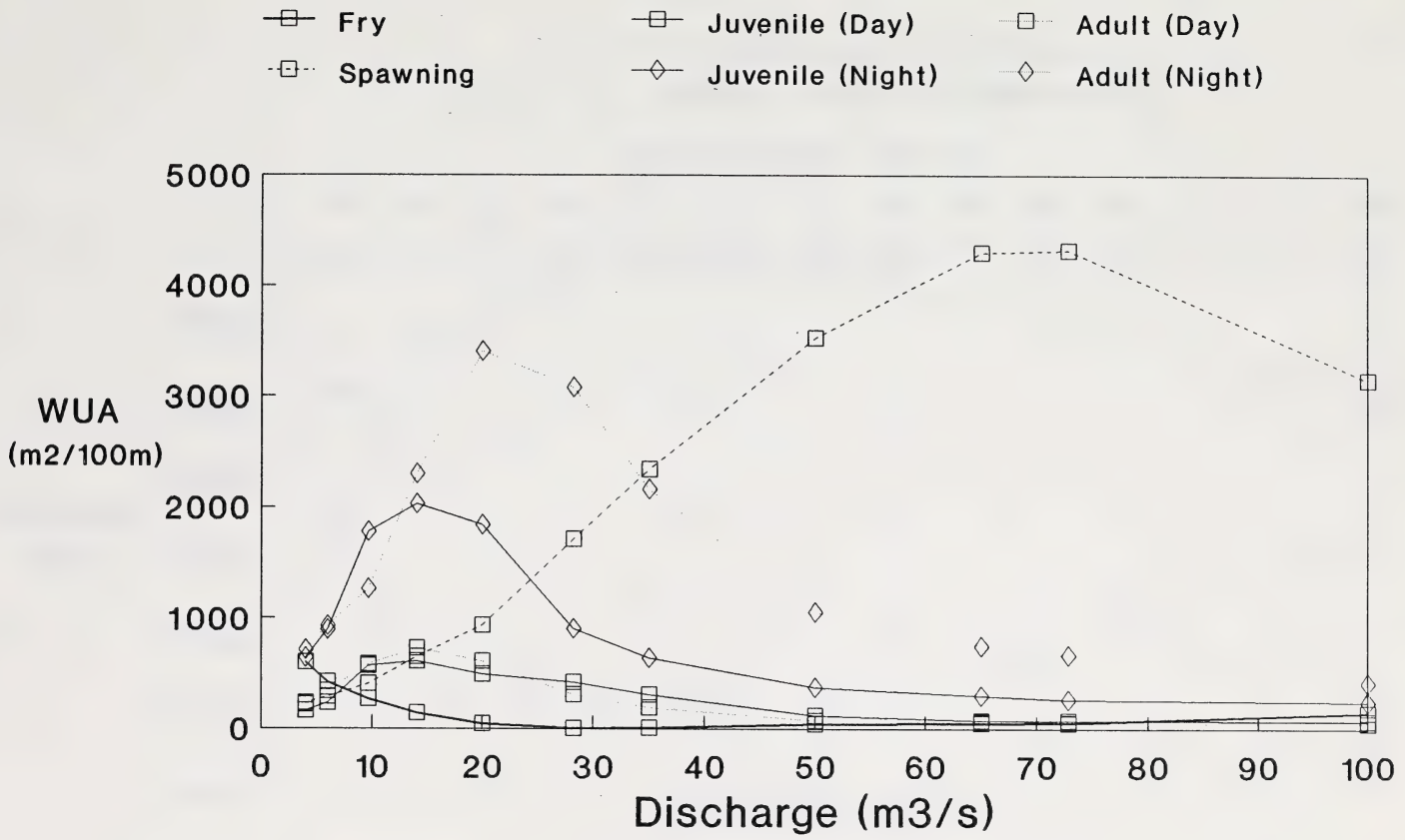



Figure 37. Walleye weighted usable area versus discharge for segment 3.

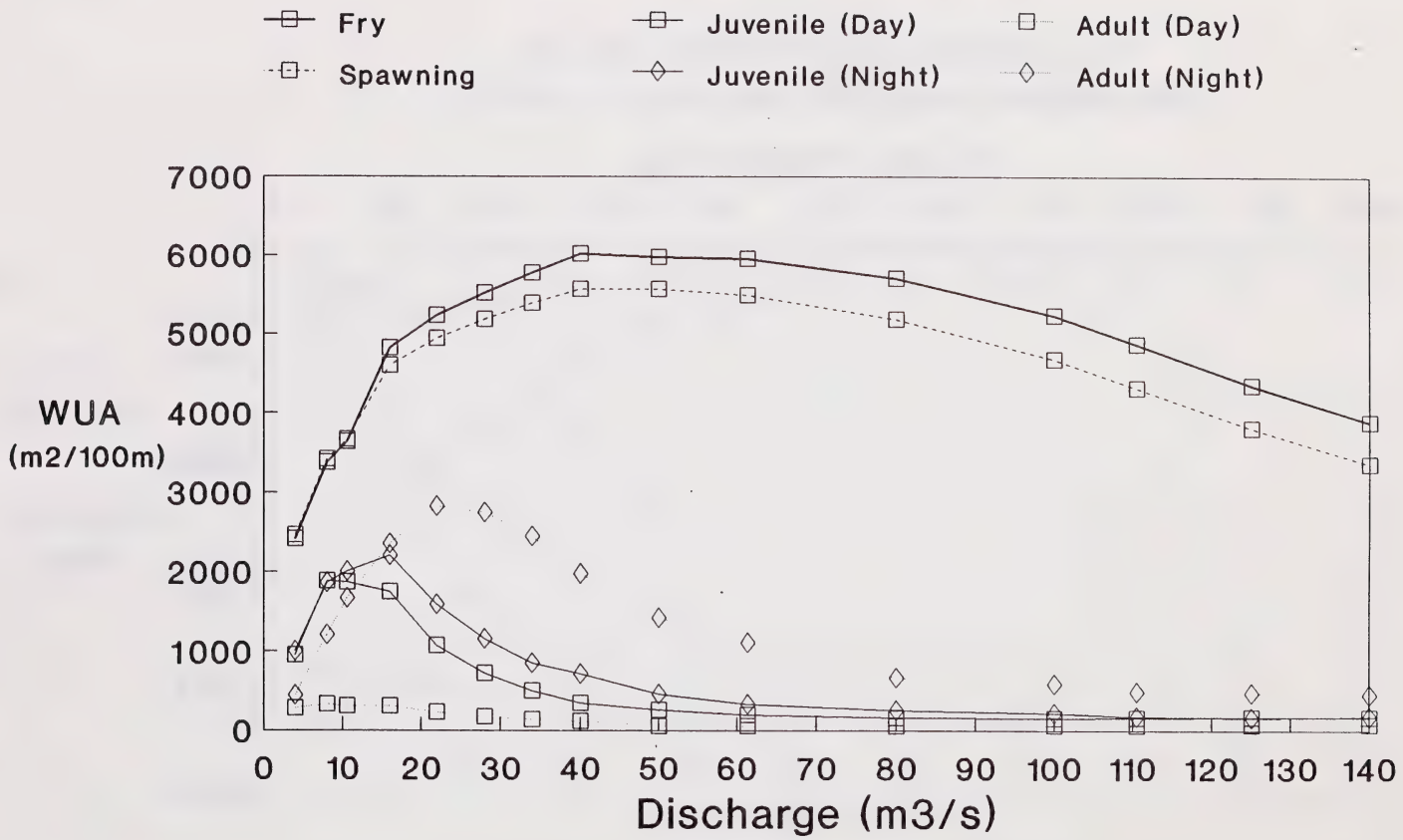



Figure 38. Sauger weighted usable area versus discharge for segment 1.

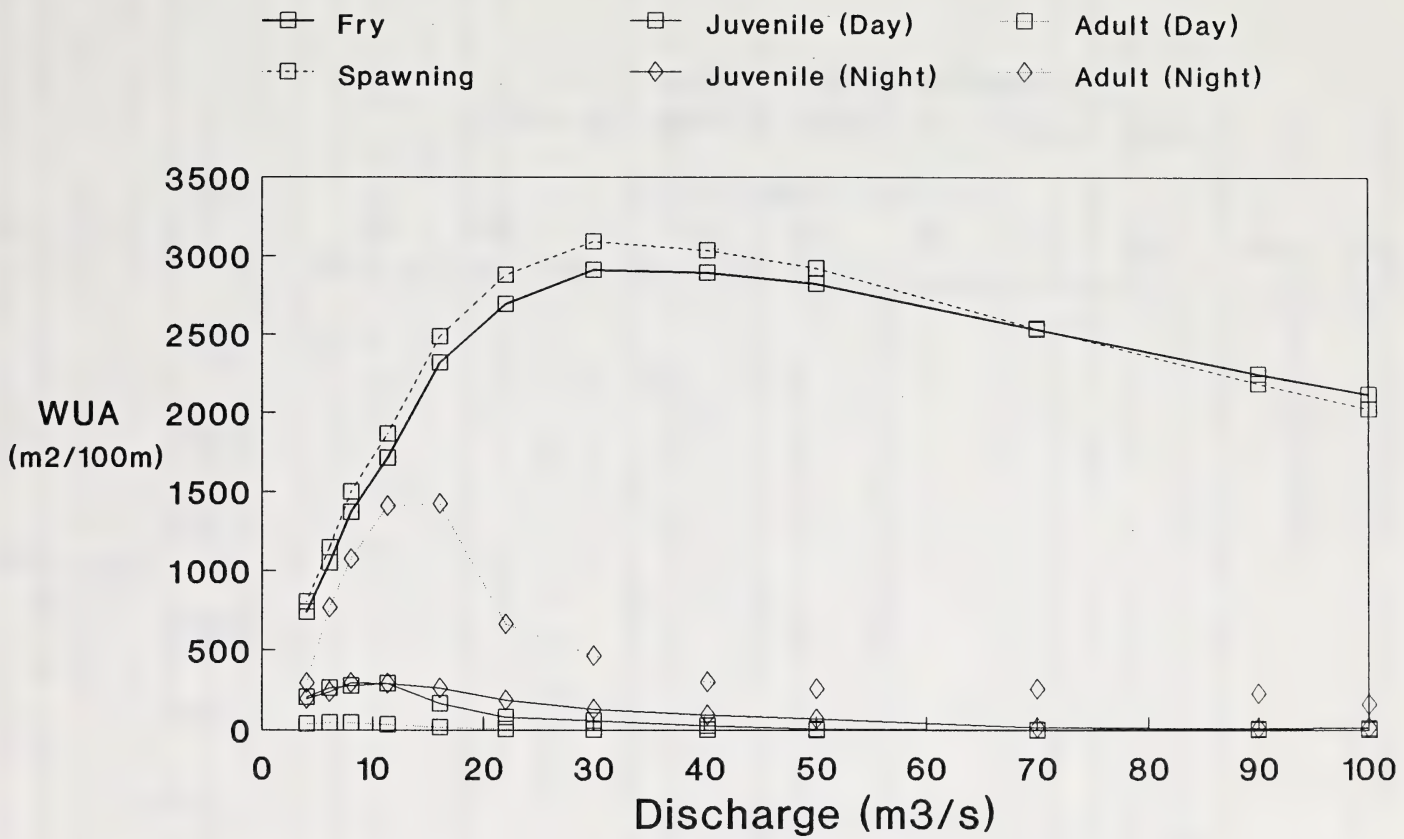



Figure 39. Sauger weighted usable area versus discharge for segment 2.

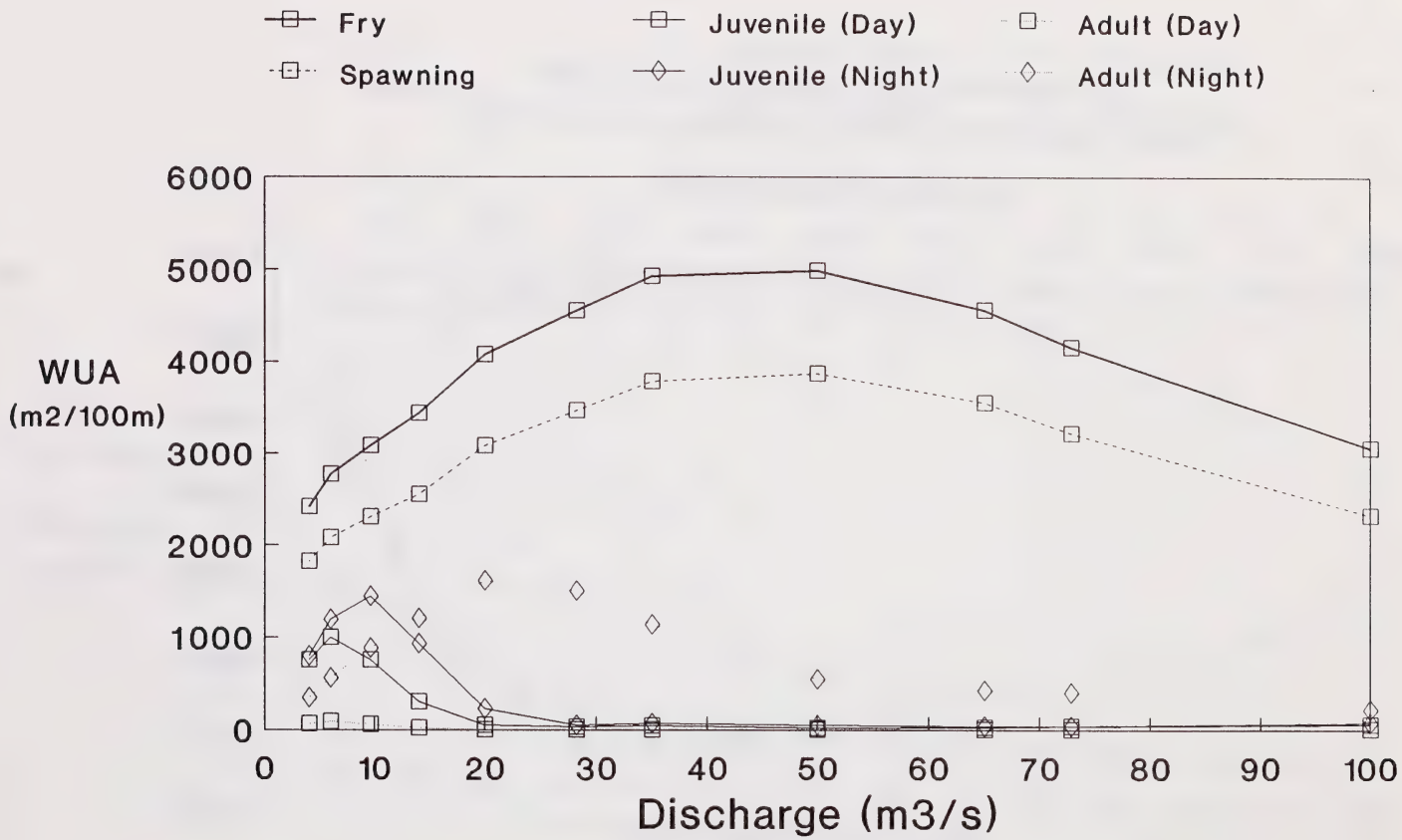



Figure 40. Sauger weighted usable area versus discharge for segment 3.

## 6.4 IDENTIFICATION OF INSTREAM FLOWS FOR FISH

### 6.4.1 Software Development

A number of computer programs were created to assist in the analysis of the habitat versus flow relationships developed with the PCSIM (PHABSIM) models. Documentation for this software is presented under separate cover. Copies of the software have been made available to the Planning Division of Alberta Environment and the Fish and Wildlife Division of Alberta Forestry, Lands and Wildlife.

### 6.4.2 Instream Flow Requirements For Fish

The concept of the Fish Rule Curve developed by the Fish and Wildlife Division was used to identify the instream flow requirements for fish in the six river segments under study. Monthly time-steps were employed for recommending streamflows, as this was the time-step in use with the water balance model.

A modification was made in the development of the curve during the low-flow months (e.g. October, November). For each time-step, the Fish Rule Curve requested optimum habitat conditions for the 10 and 20 percent exceedence flows. If optimum habitat conditions (as defined by flow) for the critical or sensitive life stage on which the rule curve was being developed did not historically occur with the natural hydrograph, the Fish Rule Curve flow request was reduced to match the natural 20 percent exceedence flow. The original Fish Rule Curve methodology specified an identical flow request for the 1 to 20 percent exceedence flows (Locke 1988). However, during the Oldman River analysis, if less than optimum conditions were being requested at the 20 percent exceedence flow, the instream flow request was increased for the 10 percent exceedence flow, either to the optimum habitat conditions or to the natural 10 percent exceedence flow value. It was judged

to be inconsistent to allow water storage or removal in the one or two wet years which were being relied upon to provide optimum conditions for the fishery resource.

Use of the Fish Rule Curve involves identifying a critical or sensitive life stage of the fauna for each time-step on which to base the evaluation. The feasibility of using the Geer approach, and developing a 'composite' fish for this purpose was also evaluated. Due to the averaging effect on habitat preference criteria which occurs with the development of a single target organism, use of the composite fish was found to have little overall sensitivity. When flow recommendations were checked against the habitat/flow relationships for individual life stages, it was found that on occasion, one or two life stages were adversely affected. This results from vastly different preferences for certain habitat characteristics by the array of life stages present (e.g., low velocity, shallow areas for fry as opposed to deeper, faster-moving waters for adults). This problem could be overcome by altering the relative weightings applied to the array of life stages present, but such a process was difficult to justify on a biological basis.

The procedure followed in the present study involved the identification of the most important life stage during each biologically significant period. During the spring (1 April through 15 June), rainbow trout spawning was identified in Segments 4, 5 and 6, while sauger spawning was utilized in Segments 1, 2 and 3 (1 April through 31 May). Sauger spawning was employed because optimal walleye spawning habitat occurs at flows in excess of 50 $m^3/s$. If flows in the 50 $m^3/s$ plus range were requested, it would be to the detriment of upstream rainbow trout spawning habitat, and the availability of habitat for other life stages of the target species which are present during the spring.

The brown trout adult life stage was employed as the most important life stage during the summer period (16 June through 30 September) in Segments 4, 5 and 6, while walleye adults were employed in Segments 1, 2 and 3 (1 June through 30 September). In all segments, brown trout spawning was the critical life stage for the fall (1 October through 30 November).

In all instances, however, the flow recommendation for each biologically significant period based on the sensitive or critical life stage in each river segment had to be compared with the habitat availability for the remaining life stages. This step in the analysis was required to ensure that the recommended flows provided suitable habitat for all the life stages present.

Fish Rule Curves were therefore generated for each biologically significant period (on a monthly time-step) at each river segment (Table 8). As the river is a continuum, the individual flow recommendations had to be integrated. For this purpose, Segment 4 (below LNID) was considered to be the critical river segment. Flows in Segments 5 and 6 (i.e., upstream of LNID) were anticipated to exceed the recommended values, due to the withdrawals which will occur at LNID and the need to meet instream flow requirements in Segment 4. Segment 4 also represented the downstream extent of coldwater habitat which would be used by rainbow trout.

Flow recommendations for Segments 1 and 2 were based on the highest value for each exceedence category in either the flow recommendation for Segments 3 and 4, or the ideal flow for that river segment. The rationale for this approach was the fact that flows may be increased at the Belly and St. Mary River confluences, and thus flow recommendations may be increased in the downstream region. Minimum flow values for the Fish Rule Curve at Segment 1 were modified to 20 $m^3/s$ throughout the open-water season, whenever

## TABLE 8

## IDEAL FISH RULE CURVES FOR EACH RIVER SEGMENT

Segment 1. Flow Exceedence Values for Naturalized and Ideal Fish Rule Curve Flows, 1912-1986

| Exceed | Apr Nat | Apr FRC | May Nat | May FRC | Jun Nat | Jun 1-15 FRC | Jun 16-30 FRC | Jul Nat | Jul FRC | Aug Nat | Aug FRC | Sep Nat | Sep FRC | Oct Nat | Oct FRC | Nov Nat | Nov FRC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.0 | 165.0 | 50.0 | 437.1 | 50.0 | 670.3 | 22.0 | 22.0 | 296.3 | 22.0 | 112.1 | 22.0 | 91.4 | 22.0 | 104.2 | 34.0 | 75.3 | 34.0 |
| 20.0 | 116.0 | 50.0 | 369.9 | 50.0 | 507.8 | 22.0 | 22.0 | 264.1 | 22.0 | 96.4 | 22.0 | 63.4 | 22.0 | 68.4 | 34.0 | 56.8 | 34.0 |
| 30.0 | 104.1 | 40.7 | 330.1 | 40.7 | 431.9 | 18.3 | 18.3 | 218.7 | 18.3 | 79.7 | 18.3 | 52.3 | 18.3 | 57.8 | 30.0 | 43.9 | 30.0 |
| 40.0 | 98.9 | 31.3 | 300.3 | 31.3 | 400.4 | 14.7 | 14.7 | 189.3 | 14.7 | 74.1 | 14.7 | 48.3 | 14.7 | 45.8 | 26.0 | 40.1 | 26.0 |
| 50.0 | 89.1 | 22.0 | 288.5 | 22.0 | 385.8 | 11.0 | 11.0 | 157.7 | 11.0 | 61.7 | 11.0 | 43.0 | 11.0 | 40.3 | 22.0 | 33.9 | 22.0 |
| 60.0 | 79.6 | 18.3 | 269.2 | 18.3 | 342.4 | 10.0 | 10.0 | 136.6 | 10.0 | 56.7 | 10.0 | 37.4 | 10.0 | 35.9 | 18.3 | 31.9 | 18.3 |
| 70.0 | 66.7 | 14.7 | 238.0 | 14.7 | 296.3 | 9.0 | 9.0 | 121.6 | 9.0 | 47.2 | 9.0 | 34.0 | 9.0 | 32.7 | 14.7 | 30.0 | 14.7 |
| 80.0 | 54.5 | 11.0 | 221.3 | 11.0 | 243.9 | 8.0 | 8.0 | 100.5 | 8.0 | 45.1 | 8.0 | 31.3 | 8.0 | 28.4 | 11.0 | 23.7 | 11.0 |
| 90.0 | 44.6 | 11.0 | 177.2 | 11.0 | 213.1 | 8.0 | 8.0 | 82.7 | 8.0 | 39.7 | 8.0 | 28.9 | 8.0 | 24.2 | 11.0 | 20.6 | 11.0 |

Segment 2. Flow Exceedence Values for Ideal Fish Rule Curve Flows, 1912-1986

| Exceed | Apr Nat | Apr FRC | May Nat | May FRC | Jun Nat | Jun 1-15 FRC | Jun 16-30 FRC | Jul Nat | Jul FRC | Aug Nat | Aug FRC | Sep Nat | Sep FRC | Oct Nat | Oct FRC | Nov Nat | Nov FRC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.0 | | 30.0 | | 30.0 | | 22.0 | 22.0 | | 22.0 | | 22.0 | | 22.0 | | 22.0 | | 22.0 |
| 20.0 | | 30.0 | | 30.0 | | 22.0 | 22.0 | | 22.0 | | 22.0 | | 22.0 | | 22.0 | | 22.0 |
| 30.0 | | 23.3 | | 23.3 | | 20.0 | 20.0 | | 20.0 | | 20.0 | | 20.0 | | 18.3 | | 18.3 |
| 40.0 | | 16.7 | | 16.7 | | 18.0 | 18.0 | | 18.0 | | 18.0 | | 18.0 | | 14.7 | | 14.7 |
| 50.0 | | 10.0 | | 10.0 | | 16.0 | 16.0 | | 16.0 | | 16.0 | | 16.0 | | 11.0 | | 11.0 |
| 60.0 | | 8.7 | | 8.7 | | 13.3 | 13.3 | | 13.3 | | 13.3 | | 13.3 | | 9.3 | | 9.3 |
| 70.0 | | 7.3 | | 7.3 | | 10.7 | 10.7 | | 10.7 | | 10.7 | | 10.7 | | 7.7 | | 7.7 |
| 80.0 | | 6.0 | | 6.0 | | 8.0 | 8.0 | | 8.0 | | 8.0 | | 8.0 | | 6.0 | | 6.0 |
| 90.0 | | 6.0 | | 6.0 | | 8.0 | 8.0 | | 8.0 | | 8.0 | | 8.0 | | 6.0 | | 6.0 |

Segment 3. Flow Exceedence Values for Naturalized and Ideal Fish Rule Curve Flows, 1912-1986

| Exceed | Apr Nat | Apr FRC | May Nat | May FRC | Jun Nat | Jun 1-15 FRC | Jun 16-30 FRC | Jul Nat | Jul FRC | Aug Nat | Aug FRC | Sep Nat | Sep FRC | Oct Nat | Oct FRC | Nov Nat | Nov FRC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.0 | 71.2 | 45.0 | 190.6 | 50.0 | 261.3 | 20.0 | 20.0 | 99.0 | 20.0 | 37.0 | 20.0 | 29.4 | 20.0 | 37.6 | 9.6 | 25.7 | 9.6 |
| 20.0 | 49.6 | 45.0 | 172.9 | 50.0 | 196.7 | 20.0 | 20.0 | 89.8 | 20.0 | 33.0 | 20.0 | 23.8 | 20.0 | 24.1 | 9.6 | 20.3 | 9.6 |
| 30.0 | 45.1 | 36.7 | 151.0 | 40.0 | 172.6 | 18.0 | 18.0 | 77.3 | 18.0 | 26.5 | 18.0 | 18.6 | 17.9 | 19.4 | 8.4 | 17.2 | 8.4 |
| 40.0 | 40.3 | 28.3 | 134.3 | 30.0 | 156.4 | 16.0 | 16.0 | 59.6 | 16.0 | 23.3 | 16.0 | 17.2 | 15.9 | 15.1 | 7.2 | 14.7 | 7.2 |
| 50.0 | 34.3 | 20.0 | 127.6 | 20.0 | 140.6 | 14.0 | 14.0 | 51.5 | 14.0 | 19.5 | 14.0 | 13.9 | 13.8 | 13.6 | 6.0 | 12.9 | 6.0 |
| 60.0 | 30.9 | 16.7 | 115.0 | 16.7 | 126.3 | 12.3 | 12.3 | 40.5 | 12.3 | 17.4 | 12.3 | 12.6 | 12.2 | 12.7 | 5.3 | 12.2 | 5.3 |
| 70.0 | 25.9 | 13.3 | 103.5 | 13.3 | 111.0 | 10.7 | 10.7 | 37.2 | 10.7 | 15.3 | 10.7 | 11.2 | 10.6 | 11.8 | 4.7 | 10.6 | 4.7 |
| 80.0 | 19.6 | 10.0 | 91.2 | 10.0 | 98.8 | 9.0 | 9.0 | 32.3 | 9.0 | 14.5 | 9.0 | 10.6 | 9.0 | 9.9 | 4.0 | 9.3 | 4.0 |
| 90.0 | 16.6 | 10.0 | 72.5 | 10.0 | 73.4 | 9.0 | 9.0 | 25.5 | 9.0 | 12.9 | 9.0 | 9.4 | 9.0 | 8.4 | 4.0 | 8.2 | 4.0 |

Segment 4. Flow Exceedence Values for Naturalized and Ideal Fish Rule Curve Flows, 1912-1986

| Exceed | Apr Nat | Apr FRC | May Nat | May FRC | Jun Nat | Jun 1-15 FRC | Jun 16-30 FRC | Jul Nat | Jul FRC | Aug Nat | Aug FRC | Sep Nat | Sep FRC | Oct Nat | Oct FRC | Nov Nat | Nov FRC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.0 | 71.2 | 27.0 | 190.6 | 27.0 | 261.3 | 27.0 | 27.0 | 99.0 | 27.0 | 37.0 | 27.0 | 29.4 | 22.0 | 37.6 | 20.0 | 25.7 | 20.0 |
| 20.0 | 49.6 | 27.0 | 172.9 | 27.0 | 196.7 | 27.0 | 27.0 | 89.8 | 27.0 | 33.0 | 27.0 | 23.8 | 22.0 | 24.1 | 20.0 | 20.3 | 20.0 |
| 30.0 | 45.1 | 23.0 | 151.0 | 23.0 | 172.6 | 23.0 | 22.7 | 77.3 | 22.7 | 26.5 | 22.7 | 18.6 | 18.6 | 19.4 | 17.5 | 17.2 | 17.1 |
| 40.0 | 40.3 | 19.0 | 134.3 | 19.0 | 156.4 | 19.0 | 18.3 | 59.6 | 18.3 | 23.3 | 18.3 | 17.2 | 16.0 | 15.1 | 15.0 | 14.7 | 14.7 |
| 50.0 | 34.3 | 15.0 | 127.6 | 15.0 | 140.6 | 15.0 | 14.0 | 51.5 | 14.0 | 19.5 | 14.0 | 13.9 | 13.0 | 13.6 | 12.5 | 12.9 | 12.5 |
| 60.0 | 30.9 | 13.3 | 115.0 | 13.3 | 126.3 | 13.3 | 12.0 | 40.5 | 12.0 | 17.4 | 12.0 | 12.6 | 11.3 | 12.7 | 11.5 | 12.2 | 11.3 |
| 70.0 | 25.9 | 11.7 | 103.5 | 11.7 | 111.0 | 11.7 | 10.0 | 37.2 | 10.0 | 15.3 | 10.0 | 11.2 | 9.7 | 11.8 | 10.5 | 10.6 | 10.2 |
| 80.0 | 19.6 | 10.0 | 91.2 | 10.0 | 98.8 | 10.0 | 8.0 | 32.3 | 8.0 | 14.5 | 8.0 | 10.6 | 8.0 | 9.9 | 9.5 | 9.3 | 9.0 |
| 90.0 | 16.6 | 10.0 | 72.5 | 10.0 | 73.4 | 10.0 | 8.0 | 25.5 | 8.0 | 12.9 | 8.0 | 9.4 | 8.0 | 8.4 | 8.0 | 8.2 | 8.0 |

Segment 5. Flow Exceedence Values for Naturalized and Ideal Fish Rule Curve Flows, 1912-1986

| Exceed | Apr Nat | Apr FRC | May Nat | May FRC | Jun Nat | Jun 1-15 FRC | Jun 16-30 FRC | Jul Nat | Jul FRC | Aug Nat | Aug FRC | Sep Nat | Sep FRC | Oct Nat | Oct FRC | Nov Nat | Nov FRC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.0 | 58.9 | 25.0 | 202.5 | 25.0 | 273.2 | 25.0 | 25.0 | 95.6 | 25.0 | 36.5 | 25.0 | 26.6 | 25.0 | 28.4 | 20.0 | 20.0 | 20.0 |
| 20.0 | 45.6 | 25.0 | 172.7 | 25.0 | 193.3 | 25.0 | 25.0 | 82.3 | 25.0 | 30.2 | 25.0 | 20.6 | 20.5 | 20.2 | 20.0 | 16.1 | 16.1 |
| 30.0 | 39.1 | 21.7 | 148.3 | 21.7 | 161.5 | 21.7 | 21.7 | 70.1 | 21.7 | 24.9 | 21.7 | 16.8 | 16.8 | 17.3 | 16.0 | 14.1 | 13.4 |
| 40.0 | 35.4 | 18.3 | 135.9 | 18.3 | 147.9 | 18.3 | 18.3 | 55.0 | 18.3 | 21.2 | 18.3 | 15.6 | 15.6 | 15.0 | 12.0 | 12.2 | 10.7 |
| 50.0 | 31.1 | 15.0 | 127.9 | 15.0 | 138.3 | 15.0 | 15.0 | 48.5 | 15.0 | 17.5 | 15.0 | 13.7 | 13.6 | 13.2 | 8.0 | 10.9 | 8.0 |
| 60.0 | 27.8 | 13.3 | 115.3 | 13.3 | 125.0 | 13.3 | 13.7 | 39.1 | 13.7 | 15.9 | 13.7 | 13.1 | 12.7 | 12.4 | 7.3 | 10.1 | 7.3 |
| 70.0 | 24.4 | 11.7 | 100.9 | 11.7 | 110.9 | 11.7 | 12.3 | 34.3 | 12.3 | 13.7 | 12.3 | 12.0 | 11.7 | 11.4 | 6.7 | 9.4 | 6.7 |
| 80.0 | 19.7 | 10.0 | 88.9 | 10.0 | 86.5 | 10.0 | 11.0 | 29.7 | 11.0 | 13.2 | 11.0 | 10.8 | 10.8 | 9.8 | 6.0 | 8.8 | 6.0 |
| 90.0 | 15.7 | 10.0 | 73.8 | 10.0 | 70.3 | 10.0 | 11.0 | 24.8 | 11.0 | 11.5 | 11.0 | 10.0 | 9.9 | 9.0 | 6.0 | 7.7 | 6.0 |

Segment 6. Flow Exceedence Values for Naturalized and Ideal Fish Rule Curve Flows, 1912-1986

| Exceed | Apr Nat | Apr FRC | May Nat | May FRC | Jun Nat | Jun 1-15 FRC | Jun 16-30 FRC | Jul Nat | Jul FRC | Aug Nat | Aug FRC | Sep Nat | Sep FRC | Oct Nat | Oct FRC | Nov Nat | Nov FRC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.0 | 58.9 | 50.0 | 202.5 | 50.0 | 273.2 | 50.0 | 21.0 | 95.6 | 21.0 | 36.5 | 21.0 | 26.6 | 21.0 | 28.4 | 15.0 | 20.0 | 15.0 |
| 20.0 | 45.6 | 45.6 | 172.7 | 50.0 | 193.3 | 50.0 | 21.0 | 82.3 | 21.0 | 30.2 | 21.0 | 20.6 | 20.5 | 20.2 | 15.0 | 16.1 | 15.0 |
| 30.0 | 39.1 | 39.1 | 148.3 | 43.3 | 161.5 | 43.3 | 17.0 | 70.1 | 17.0 | 24.9 | 17.0 | 16.8 | 16.7 | 17.3 | 12.3 | 14.1 | 12.3 |
| 40.0 | 35.4 | 35.4 | 135.9 | 36.7 | 147.9 | 36.7 | 13.0 | 55.0 | 13.0 | 21.2 | 13.0 | 15.6 | 12.8 | 15.0 | 9.7 | 12.2 | 9.7 |
| 50.0 | 31.1 | 30.0 | 127.9 | 30.0 | 138.3 | 30.0 | 9.0 | 48.5 | 9.0 | 17.5 | 9.0 | 13.7 | 9.0 | 13.2 | 7.0 | 10.9 | 7.0 |
| 60.0 | 27.8 | 26.6 | 115.3 | 28.3 | 125.0 | 28.3 | 9.0 | 39.1 | 9.0 | 15.9 | 9.0 | 13.1 | 9.0 | 12.4 | 7.0 | 10.1 | 7.0 |
| 70.0 | 24.4 | 23.1 | 100.9 | 26.7 | 110.9 | 26.7 | 9.0 | 34.3 | 9.0 | 13.7 | 9.0 | 12.0 | 9.0 | 11.4 | 7.0 | 9.4 | 7.0 |
| 80.0 | 19.7 | 19.7 | 88.9 | 25.0 | 86.5 | 25.0 | 9.0 | 29.7 | 9.0 | 13.2 | 9.0 | 10.8 | 9.0 | 9.8 | 7.0 | 8.8 | 7.0 |
| 90.0 | 15.7 | 15.7 | 73.8 | 25.0 | 70.3 | 25.0 | 9.0 | 24.8 | 9.0 | 11.5 | 9.0 | 10.0 | 9.0 | 9.0 | 7.0 | 7.7 | 7.0 |

values fell below this value, in recognition of the requirement to meet water quality standards below the City of Lethbridge (HydroQual 1990). Segment 3 flow recommendations were largely based on the Fish Rule Curve developed for Segment 4, as there are no significant inflows between Segments 3 and 4 (Figure 2). The overall flow recommendations for the fishery resource are summarized in Table 9.

During the period of ice-cover, the flow recommended for maintenance of water quality criteria in Segment 1 (11.5 $m^3/s$) was adopted, as instream flow requirements during this season will be based on maintaining suitable water quality standards for the winter months. Upstream of Segment 1, the minimum requirement for the winter months of 8.5 $m^3/s$ which was employed in the Water Balance Model (OD05) was evaluated as meeting fisheries needs. This discharge rate is anticipated to provide suitable water quality for the fishery resource (HydroQual 1990), and is within the range of flows which normally occur in the Oldman River during the winter season. For example, the recorded range in monthly mean discharge for the Oldman River near Fort Macleod (WSC Station No. 05AB007), for the period of operation for that station (1910 to 1948), was 4.30 to 24.2 $m^3/s$. The mean monthly flows ($m^3/s$) for the months of December, January and February for this station and period of record are 11.2, 9.38 and 9.71, respectively.

### 6.4.3 Habitat Availability Under Various Flow Regimes

The approach employed to analyze alternative flow regimes was the comparison of area under the habitat duration curves for the 'composite' fish. The weighted usable area versus discharge curve developed for the composite fish is a definition of how habitat availability changes with flow for all the life stages of the target species present for each time-step in the analysis. This relationship therefore reflects the optimum, average and minimum discharges associated with the optimal, average and minimum

## TABLE 9
## RECOMMENDED FISH RULE CURVES FOR EACH RIVER SEGMENT

Segment 1. Flow Exceedence Values for Naturalized and Recommended Fish Rule Curve Flows, 1912-1986

| Exceed | Apr Nat | Apr FRC | May Nat | May FRC | Jun Nat | Jun 1-15 FRC | Jun 16-30 FRC | Jul Nat | Jul FRC | Aug Nat | Aug FRC | Sep Nat | Sep FRC | Oct Nat | Oct FRC | Nov Nat | Nov FRC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.0 | 165.0 | 50.0 | 437.1 | 50.0 | 670.3 | 40.0 | 27.0 | 296.3 | 27.0 | 112.1 | 27.0 | 91.4 | 22.0 | 104.2 | 34.0 | 75.3 | 34.0 |
| 20.0 | 116.0 | 50.0 | 369.9 | 50.0 | 507.8 | 40.0 | 27.0 | 264.1 | 27.0 | 96.4 | 27.0 | 63.4 | 22.0 | 68.4 | 34.0 | 56.8 | 34.0 |
| 30.0 | 104.1 | 40.7 | 330.1 | 40.7 | 431.9 | 33.3 | 22.7 | 218.7 | 22.7 | 79.7 | 22.7 | 52.3 | 20.0 | 57.8 | 30.0 | 43.9 | 30.0 |
| 40.0 | 98.9 | 31.3 | 300.3 | 31.3 | 400.4 | 26.7 | 20.0 | 189.3 | 20.0 | 74.1 | 20.0 | 48.3 | 20.0 | 45.8 | 26.0 | 40.1 | 26.0 |
| 50.0 | 89.1 | 22.0 | 288.5 | 22.0 | 385.8 | 20.0 | 20.0 | 157.7 | 20.0 | 61.7 | 20.0 | 43.0 | 20.0 | 40.3 | 22.0 | 33.9 | 22.0 |
| 60.0 | 79.6 | 20.0 | 269.2 | 20.0 | 342.4 | 20.0 | 20.0 | 136.6 | 20.0 | 56.7 | 20.0 | 37.4 | 20.0 | 35.9 | 20.0 | 31.9 | 20.0 |
| 70.0 | 66.7 | 20.0 | 238.0 | 20.0 | 296.3 | 20.0 | 20.0 | 121.6 | 20.0 | 47.2 | 20.0 | 34.0 | 20.0 | 32.7 | 20.0 | 30.0 | 20.0 |
| 80.0 | 54.5 | 20.0 | 221.3 | 20.0 | 243.9 | 20.0 | 20.0 | 100.5 | 20.0 | 45.1 | 20.0 | 31.3 | 20.0 | 28.4 | 20.0 | 23.7 | 20.0 |
| 90.0 | 44.6 | 20.0 | 177.2 | 20.0 | 213.1 | 20.0 | 20.0 | 82.7 | 20.0 | 39.7 | 20.0 | 28.9 | 20.0 | 24.2 | 20.0 | 20.6 | 20.0 |

Segment 2. Flow Exceedence Values for Recommended Fish Rule Curve Flows (Naturalized Flows Were, 1912-1986

| Exceed | Apr Nat | Apr FRC | May Nat | May FRC | Jun Nat | Jun 1-15 FRC | Jun 16-30 FRC | Jul Nat | Jul FRC | Aug Nat | Aug FRC | Sep Nat | Sep FRC | Oct Nat | Oct FRC | Nov Nat | Nov FRC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.0 | | 27.0 | | 27.0 | | 27.0 | 27.0 | | 27.0 | | 27.0 | | 22.0 | | 22.0 | | 22.0 |
| 20.0 | | 27.0 | | 27.0 | | 27.0 | 27.0 | | 27.0 | | 27.0 | | 22.0 | | 22.0 | | 22.0 |
| 30.0 | | 23.0 | | 23.0 | | 23.3 | 22.7 | | 22.7 | | 22.7 | | 18.6 | | 18.3 | | 18.3 |
| 40.0 | | 19.0 | | 19.0 | | 19.7 | 18.3 | | 18.3 | | 18.3 | | 16.0 | | 15.0 | | 14.7 |
| 50.0 | | 15.0 | | 15.0 | | 16.0 | 16.0 | | 16.0 | | 16.0 | | 16.0 | | 12.5 | | 12.5 |
| 60.0 | | 13.3 | | 13.3 | | 14.0 | 13.3 | | 13.3 | | 13.3 | | 13.3 | | 11.5 | | 11.5 |
| 70.0 | | 11.7 | | 11.7 | | 12.0 | 10.7 | | 10.7 | | 10.7 | | 10.7 | | 10.5 | | 10.2 |
| 80.0 | | 10.0 | | 10.0 | | 10.0 | 8.0 | | 8.0 | | 8.0 | | 8.0 | | 9.5 | | 9.0 |
| 90.0 | | 10.0 | | 10.0 | | 10.0 | 8.0 | | 8.0 | | 8.0 | | 8.0 | | 8.0 | | 8.0 |

Segment 3. Flow Exceedence Values for Naturalized and Recommended Fish Rule Curve Flows, 1912-1986

| Exceed | Apr Nat | Apr FRC | May Nat | May FRC | Jun Nat | Jun 1-15 FRC | Jun 16-30 FRC | Jul Nat | Jul FRC | Aug Nat | Aug FRC | Sep Nat | Sep FRC | Oct Nat | Oct FRC | Nov Nat | Nov FRC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.0 | 71.2 | 27.0 | 190.6 | 27.0 | 261.3 | 27.0 | 27.0 | 99.0 | 27.0 | 37.0 | 27.0 | 29.4 | 22.0 | 37.6 | 20.0 | 25.7 | 20.0 |
| 20.0 | 49.6 | 27.0 | 172.9 | 27.0 | 196.7 | 27.0 | 27.0 | 89.8 | 27.0 | 33.0 | 27.0 | 23.8 | 22.0 | 24.1 | 20.0 | 20.3 | 20.0 |
| 30.0 | 45.1 | 23.0 | 151.0 | 23.0 | 172.6 | 23.0 | 22.7 | 77.3 | 22.7 | 26.5 | 22.7 | 18.6 | 18.6 | 19.4 | 17.5 | 17.2 | 17.1 |
| 40.0 | 40.3 | 19.0 | 134.3 | 19.0 | 156.4 | 19.0 | 18.3 | 59.6 | 18.3 | 23.3 | 18.3 | 17.2 | 16.0 | 15.1 | 15.0 | 14.7 | 14.7 |
| 50.0 | 34.3 | 15.0 | 127.6 | 15.0 | 140.6 | 15.0 | 14.0 | 51.5 | 14.0 | 19.5 | 14.0 | 13.9 | 13.0 | 13.6 | 12.5 | 12.9 | 12.5 |
| 60.0 | 30.9 | 13.3 | 115.0 | 13.3 | 126.3 | 13.3 | 12.0 | 40.5 | 12.0 | 17.4 | 12.0 | 12.6 | 11.3 | 12.7 | 11.5 | 12.2 | 11.3 |
| 70.0 | 25.9 | 11.7 | 103.5 | 11.7 | 111.0 | 11.7 | 10.0 | 37.2 | 10.0 | 15.3 | 10.0 | 11.2 | 9.7 | 11.8 | 10.5 | 10.6 | 10.2 |
| 80.0 | 19.6 | 10.0 | 91.2 | 10.0 | 98.8 | 10.0 | 8.0 | 32.3 | 8.0 | 14.5 | 8.0 | 10.6 | 8.0 | 9.9 | 9.5 | 9.3 | 9.0 |
| 90.0 | 16.6 | 10.0 | 72.5 | 10.0 | 73.4 | 10.0 | 8.0 | 25.5 | 8.0 | 12.9 | 8.0 | 9.4 | 8.0 | 8.4 | 8.0 | 8.2 | 8.0 |

Segment 4. Flow Exceedence Values for Naturalized and Recommended Fish Rule Curve Flows, 1912-1986

| Exceed | Apr Nat | Apr FRC | May Nat | May FRC | Jun Nat | Jun 1-15 FRC | Jun 16-30 FRC | Jul Nat | Jul FRC | Aug Nat | Aug FRC | Sep Nat | Sep FRC | Oct Nat | Oct FRC | Nov Nat | Nov FRC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.0 | 71.2 | 27.0 | 190.6 | 27.0 | 261.3 | 27.0 | 27.0 | 99.0 | 27.0 | 37.0 | 27.0 | 29.4 | 22.0 | 37.6 | 20.0 | 25.7 | 20.0 |
| 20.0 | 49.6 | 27.0 | 172.9 | 27.0 | 196.7 | 27.0 | 27.0 | 89.8 | 27.0 | 33.0 | 27.0 | 23.8 | 22.0 | 24.1 | 20.0 | 20.3 | 20.0 |
| 30.0 | 45.1 | 23.0 | 151.0 | 23.0 | 172.6 | 23.0 | 22.7 | 77.3 | 22.7 | 26.5 | 22.7 | 18.6 | 18.6 | 19.4 | 17.5 | 17.2 | 17.1 |
| 40.0 | 40.3 | 19.0 | 134.3 | 19.0 | 156.4 | 19.0 | 18.3 | 59.6 | 18.3 | 23.3 | 18.3 | 17.2 | 16.0 | 15.1 | 15.0 | 14.7 | 14.7 |
| 50.0 | 34.3 | 15.0 | 127.6 | 15.0 | 140.6 | 15.0 | 14.0 | 51.5 | 14.0 | 19.5 | 14.0 | 13.9 | 13.0 | 13.6 | 12.5 | 12.9 | 12.5 |
| 60.0 | 30.9 | 13.3 | 115.0 | 13.3 | 126.3 | 13.3 | 12.0 | 40.5 | 12.0 | 17.4 | 12.0 | 12.6 | 11.3 | 12.7 | 11.5 | 12.2 | 11.3 |
| 70.0 | 25.9 | 11.7 | 103.5 | 11.7 | 111.0 | 11.7 | 10.0 | 37.2 | 10.0 | 15.3 | 10.0 | 11.2 | 9.7 | 11.8 | 10.5 | 10.6 | 10.2 |
| 80.0 | 19.6 | 10.0 | 91.2 | 10.0 | 98.8 | 10.0 | 8.0 | 32.3 | 8.0 | 14.5 | 8.0 | 10.6 | 8.0 | 9.9 | 9.5 | 9.3 | 9.0 |
| 90.0 | 16.6 | 10.0 | 72.5 | 10.0 | 73.4 | 10.0 | 8.0 | 25.5 | 8.0 | 12.9 | 8.0 | 9.4 | 8.0 | 8.4 | 8.0 | 8.2 | 8.0 |

Segment 5. Flow Exceedence Values for Naturalized and Recommended Fish Rule Curve Flows, 1912-1986

| Exceed | Apr Nat | Apr FRC | May Nat | May FRC | Jun Nat | Jun 1-15 FRC | Jun 16-30 FRC | Jul Nat | Jul FRC | Aug Nat | Aug FRC | Sep Nat | Sep FRC | Oct Nat | Oct FRC | Nov Nat | Nov FRC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.0 | 58.9 | 27.0 | 202.5 | 27.0 | 273.2 | 27.0 | 27.0 | 95.6 | 27.0 | 36.5 | 27.0 | 26.6 | 22.0 | 28.4 | 20.0 | 20.0 | 20.0 |
| 20.0 | 45.6 | 27.0 | 172.7 | 27.0 | 193.3 | 27.0 | 27.0 | 82.3 | 27.0 | 30.2 | 27.0 | 20.6 | 22.0 | 20.2 | 20.0 | 16.1 | 20.0 |
| 30.0 | 39.1 | 23.0 | 148.3 | 23.0 | 161.5 | 23.0 | 22.7 | 70.1 | 22.7 | 24.9 | 22.7 | 16.8 | 18.6 | 17.3 | 17.5 | 14.1 | 17.1 |
| 40.0 | 35.4 | 19.0 | 135.9 | 19.0 | 147.9 | 19.0 | 18.3 | 55.0 | 18.3 | 21.2 | 18.3 | 15.6 | 16.0 | 15.0 | 15.0 | 12.2 | 14.7 |
| 50.0 | 31.1 | 15.0 | 127.9 | 15.0 | 138.3 | 15.0 | 14.0 | 48.5 | 14.0 | 17.5 | 14.0 | 13.7 | 13.0 | 13.2 | 12.5 | 10.9 | 12.5 |
| 60.0 | 27.8 | 13.3 | 115.3 | 13.3 | 125.0 | 13.3 | 12.0 | 39.1 | 12.0 | 15.9 | 12.0 | 13.1 | 11.3 | 12.4 | 11.5 | 10.1 | 11.3 |
| 70.0 | 24.4 | 11.7 | 100.9 | 11.7 | 110.9 | 11.7 | 10.0 | 34.3 | 10.0 | 13.7 | 10.0 | 12.0 | 9.7 | 11.4 | 10.5 | 9.4 | 10.2 |
| 80.0 | 19.7 | 10.0 | 88.9 | 10.0 | 86.5 | 10.0 | 8.0 | 29.7 | 8.0 | 13.2 | 8.0 | 10.8 | 8.0 | 9.8 | 9.5 | 8.8 | 9.0 |
| 90.0 | 15.7 | 10.0 | 73.8 | 10.0 | 70.3 | 10.0 | 8.0 | 24.8 | 8.0 | 11.5 | 8.0 | 10.0 | 8.0 | 9.0 | 8.0 | 7.7 | 8.0 |

Segment 6. Flow Exceedence Values for Naturalized and Recommended Fish Rule Curve Flows, 1912-1986

| Exceed | Apr Nat | Apr FRC | May Nat | May FRC | Jun Nat | Jun 1-15 FRC | Jun 16-30 FRC | Jul Nat | Jul FRC | Aug Nat | Aug FRC | Sep Nat | Sep FRC | Oct Nat | Oct FRC | Nov Nat | Nov FRC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.0 | 58.9 | 27.0 | 202.5 | 27.0 | 273.2 | 27.0 | 27.0 | 95.6 | 27.0 | 36.5 | 27.0 | 26.6 | 22.0 | 28.4 | 20.0 | 20.0 | 20.0 |
| 20.0 | 45.6 | 27.0 | 172.7 | 27.0 | 193.3 | 27.0 | 27.0 | 82.3 | 27.0 | 30.2 | 27.0 | 20.6 | 22.0 | 20.2 | 20.0 | 16.1 | 20.0 |
| 30.0 | 39.1 | 23.0 | 148.3 | 23.0 | 161.5 | 23.0 | 22.7 | 70.1 | 22.7 | 24.9 | 22.7 | 16.8 | 18.6 | 17.3 | 17.5 | 14.1 | 17.1 |
| 40.0 | 35.4 | 19.0 | 135.9 | 19.0 | 147.9 | 19.0 | 18.3 | 55.0 | 18.3 | 21.2 | 18.3 | 15.6 | 16.0 | 15.0 | 15.0 | 12.2 | 14.7 |
| 50.0 | 31.1 | 15.0 | 127.9 | 15.0 | 138.3 | 15.0 | 14.0 | 48.5 | 14.0 | 17.5 | 14.0 | 13.7 | 13.0 | 13.2 | 12.5 | 10.9 | 12.5 |
| 60.0 | 27.8 | 13.3 | 115.3 | 13.3 | 125.0 | 13.3 | 12.0 | 39.1 | 12.0 | 15.9 | 12.0 | 13.1 | 11.3 | 12.4 | 11.5 | 10.1 | 11.3 |
| 70.0 | 24.4 | 11.7 | 100.9 | 11.7 | 110.9 | 11.7 | 10.0 | 34.3 | 10.0 | 13.7 | 10.0 | 12.0 | 9.7 | 11.4 | 10.5 | 9.4 | 10.2 |
| 80.0 | 19.7 | 10.0 | 88.9 | 10.0 | 86.5 | 10.0 | 8.0 | 29.7 | 8.0 | 13.2 | 8.0 | 10.8 | 8.0 | 9.8 | 9.5 | 8.8 | 9.0 |
| 90.0 | 15.7 | 10.0 | 73.8 | 10.0 | 70.3 | 10.0 | 8.0 | 24.8 | 8.0 | 11.5 | 8.0 | 10.0 | 8.0 | 9.0 | 8.0 | 7.7 | 8.0 |

habitat values used for the species assemblage used in the development of the Fish Rule Curve. The areas under the habitat duration curves for the flow regimes examined therefore provides a basis for comparison of habitat gains or losses for the array of species and life stages (as represented by the composite fish) of interest.

The flow regimes which were analyzed were the recorded hydrograph, the 'naturalized' hydrograph, and ODO5 output. This analysis is presented graphically in Figures 41 through 45. In addition to providing an indication of habitat availability over the open-water period, the habitat duration analyses for three representative months (May, August, October) are also illustrated on these figures. The areas under the curves (which are unitless) are presented in Table 10 to facilitate a quantitative evaluation of this measure of habitat availability. In addition to a comparison of total areas (i.e. total for the range of 10 to 90 percent exceedences) under each habitat duration curve, the area under the 50 to 90 percent exceedence range is also presented to illustrate differences under average to low habitat conditions. This comparison could not be conducted for Segment 2, as naturalized and ODO5 flow simulations were not available for the region of the river between the Belly and St. Mary confluences.

This analysis is based on the assumption that inherent in the creation of the composite fish is the provision of cover for the salmonids downstream of the damsite.

### 6.4.4 Flushing Flow Requirements

The analysis of flushing flow requirements for the Oldman River is addressed in J.N. MacKenzie Ltd. (1989). The results of this evaluation indicate the following 24 hour peak flows for an 8-

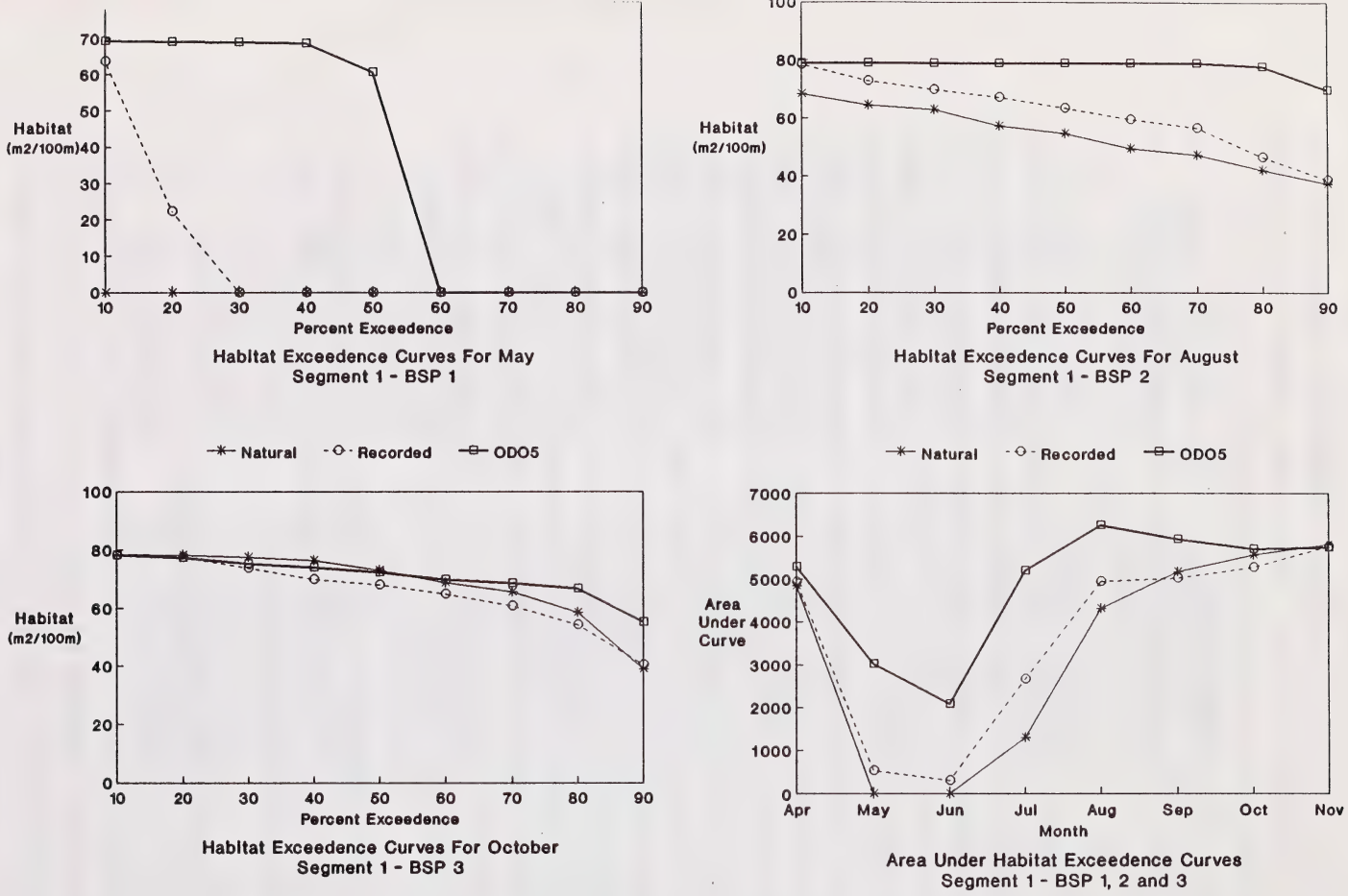



Figure 41. Habitat exceedence curves for the composite fish in segment 1 of the Oldman River.

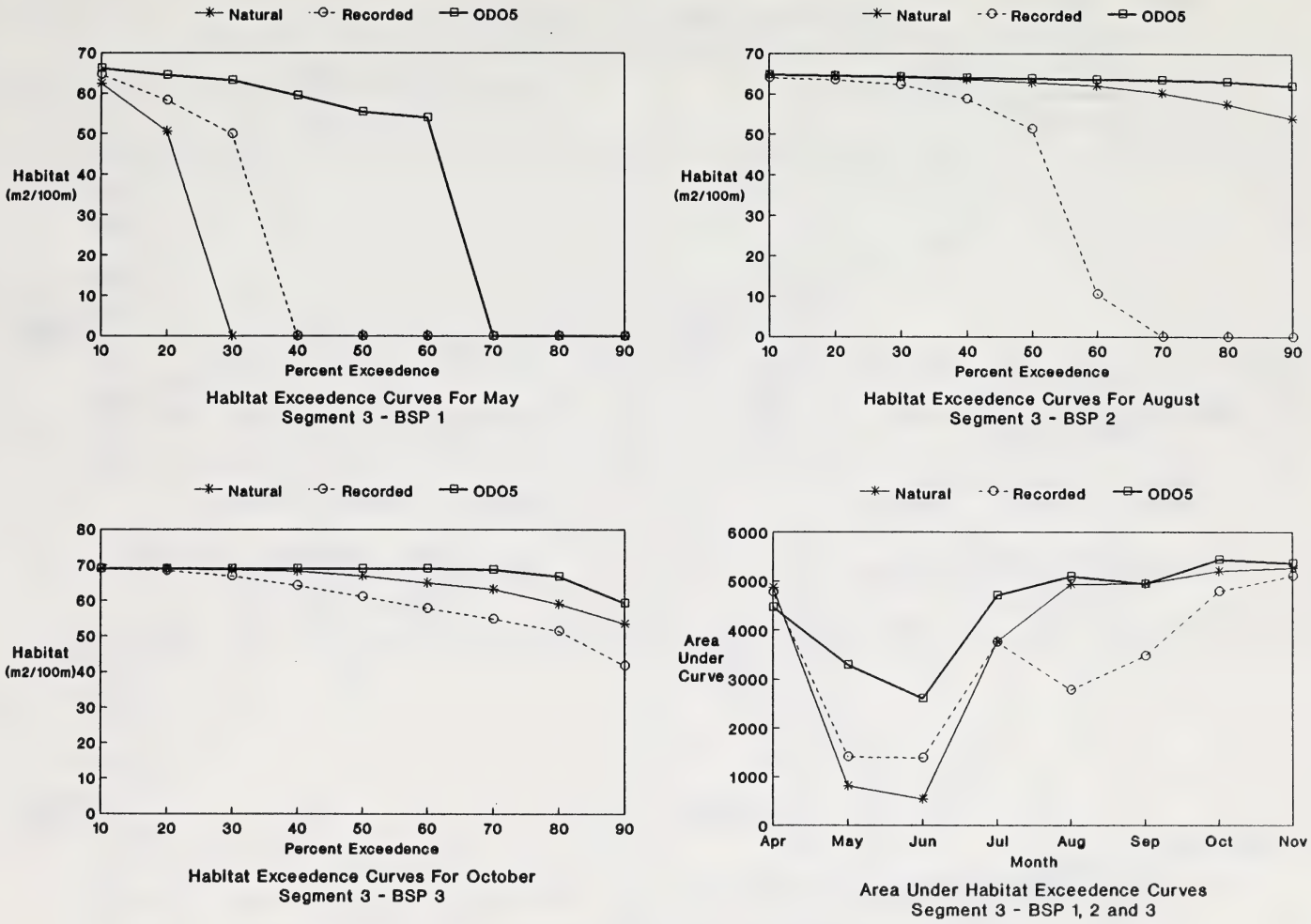
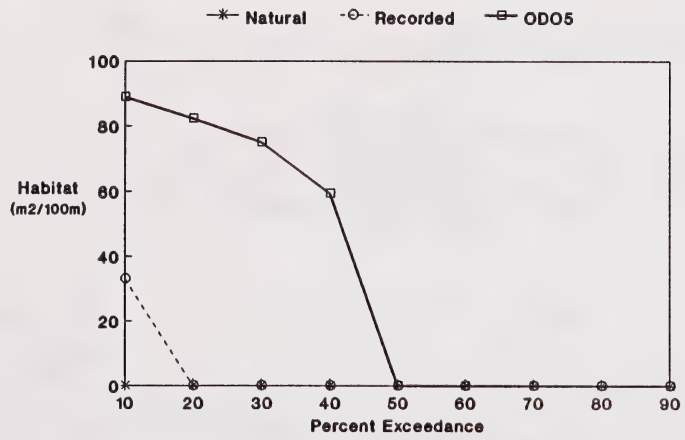
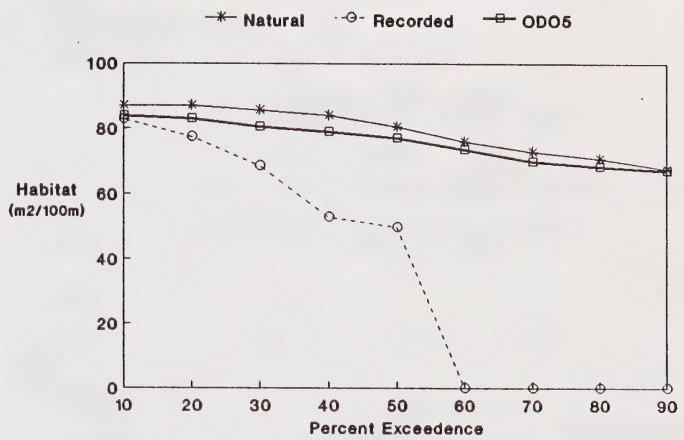


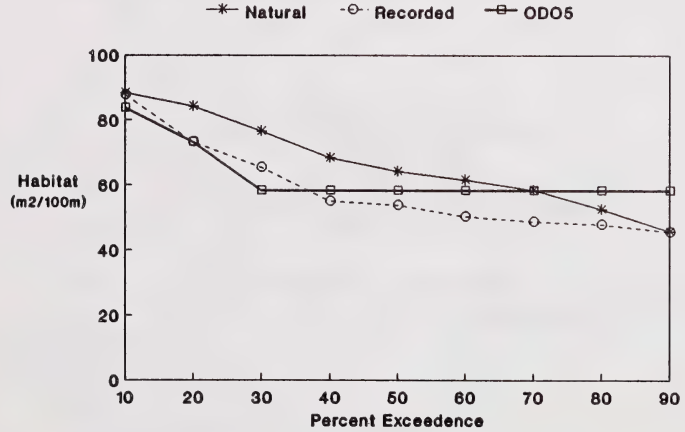

Figure 42. Habitat exceedence curves for the composite fish in segment 3 of the Oldman River.



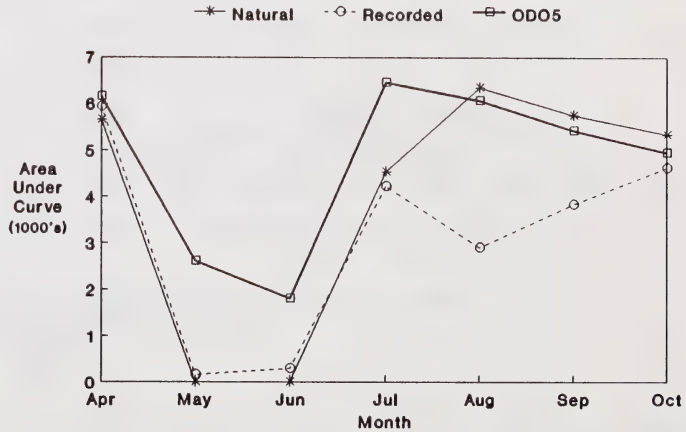

Habitat Exceedence Curves For May
Segment 4 - BSP 1




Habitat Exceedence Curves For August
Segment 4 - BSP 2

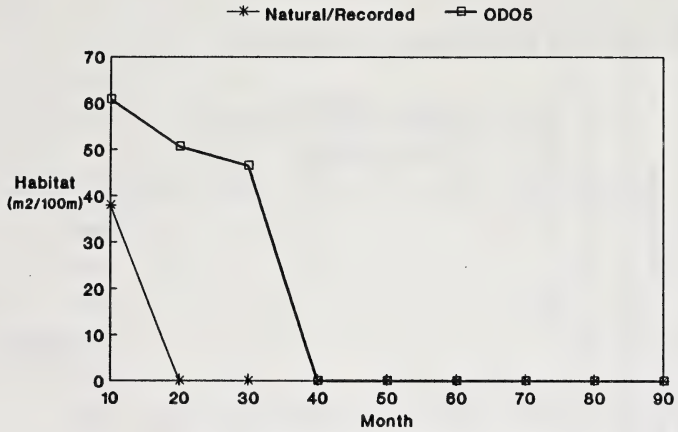



Habitat Exceedence Curves For October
Segment 4 - BSP 3

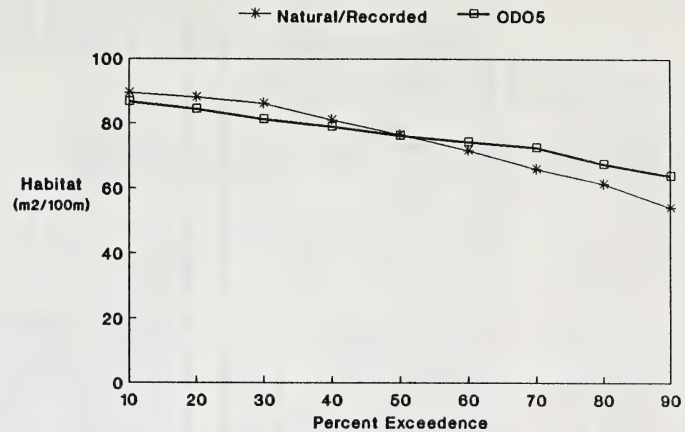



Area Under Habitat Exceedence Curves
Segment 4 - BSP 1, 2 and 3

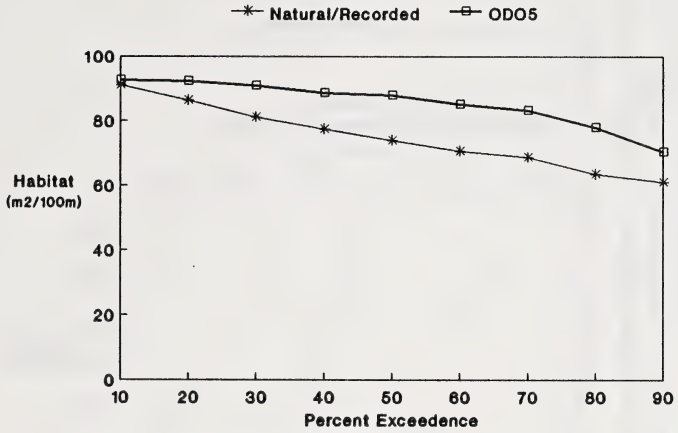
Figure 43. Habitat exceedence curves for the composite fish in segment 4 of the Oldman River.



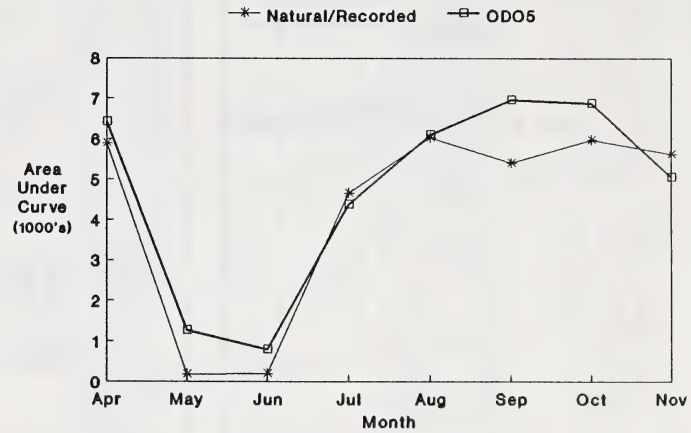

Habitat Exceedence Curves For May
Segment 5 - BSP 1




Habitat Exceedence Curves For August
Segment 5 - BSP 2

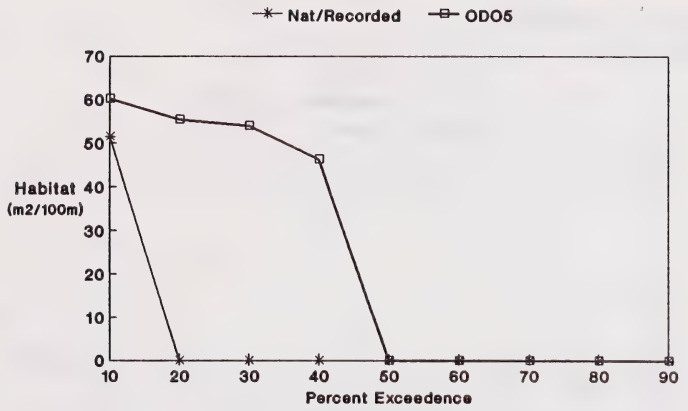



Habitat Exceedence Curves For October
Segment 5 - BSP 3

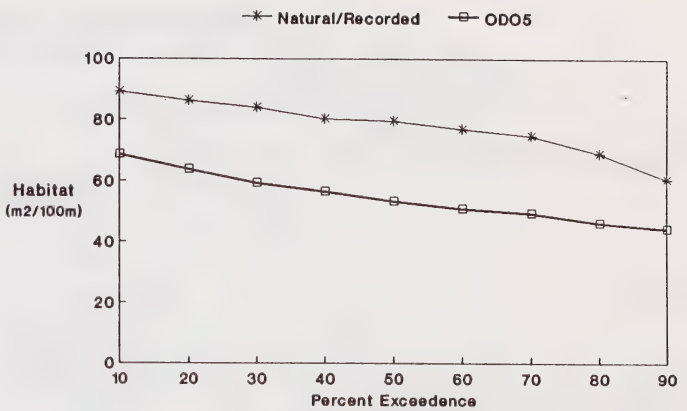



Area Under Habitat Exceedence Curves
Segment 5 - BSP 1, 2 and 3

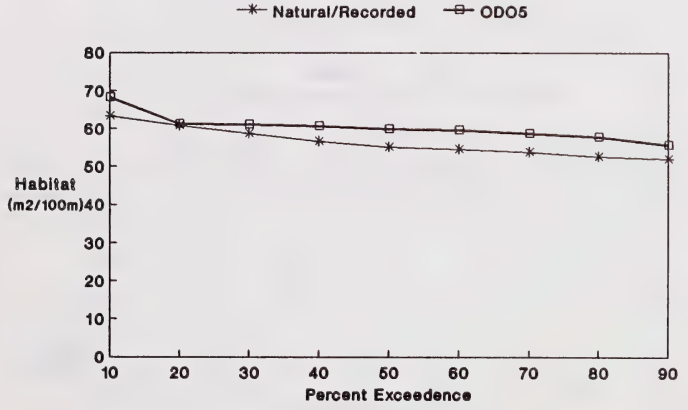
Figure 44. Habitat exceedence curves for the composite fish in segment 5 of the Oldman River.



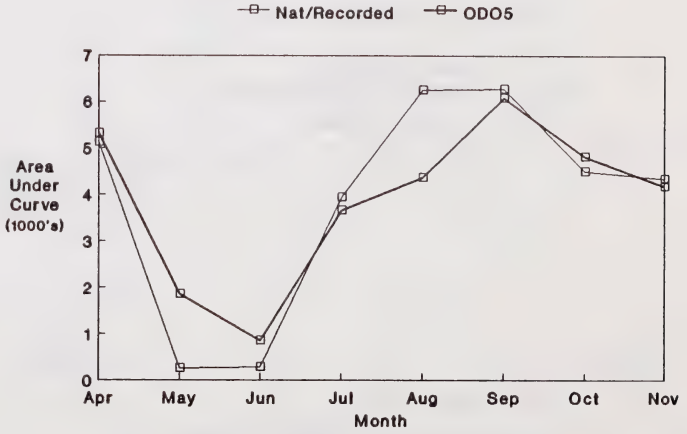

Habitat Exceedence Curves For May
Segment 6 - BSP 1




Habitat Exceedence Curves For August
Segment 6 - BSP 2




Habitat Exceedence Curves For October
Segment 6 - BSP 3




Area Under Habitat Exceedence Curves
Segment 6 - BSP 1, 2 and 3

Figure 45. Habitat exceedence curves for the composite fish in segment 6 of the Oldman River.

## TABLE 10

## A RELATIVE COMPARISON OF HABITAT AVAILABILITY[1] FOR THE NATURAL, RECORDED AND ODO5 FLOW REGIMES FOR THE 10-90% AND 50-90% HABITAT EXCEEDENCE CURVES

| Area Under 10-90% Exceedence Curves | | | | | |
|---|---|---|---|---|---|
| Flow Regime | Segment 1 | Segment 3 | Segment 4 | Segment 5 | Segment 6 |
| Natural | 21691 | 25282 | 22124 | 28217 | 26226 |
| Recorded | 24127 | 22538 | 16678 | 28217 | 26226 |
| ODO5 | 33715 | 31020 | 27919 | 32139 | 26364 |

| Area Under 50-90% Exceedence Curves | | | | | |
|---|---|---|---|---|---|
| Flow Regime | Segment 1 | Segment 3 | Segment 4 | Segment 5 | Segment 6 |
| Natural | 12096 | 13864 | 8132 | 11606 | 11539 |
| Recorded | 12623 | 9787 | 3889 | 11606 | 11539 |
| ODO5 | 16276 | 15727 | 10219 | 13909 | 11022 |

[1] The comparison is based on area under the habitat exceedence graphs, and is therefore unitless.

requirements: Segment 6 - 300 $m^3/s$; Segment 5 - 300 $m^3/s$; Segment 4 - 300 $m^3/s$; Segment 3 - 500 $m^3/s$; Segment 2 - 500 $m^3/s$; and, Segment 1 - 1,200 $m^3/s$. The required frequency for flushing flows was estimated to be between two and five years. These flushing flow requirements are met with the OD05 flow simulation.

# 7.0 DISCUSSION

## 7.1 EVALUATION OF WATER BALANCE SIMULATIONS

The streamflow recommendations developed for the Oldman River downstream of the damsite are based on the best-available information at the time of the analysis. The applicability of sauger spawning and fry habitat preferences, walleye fry habitat preferences and to a lesser extent, walleye spawning habitat preferences used in this analysis may not be evaluated, as these life stages apparently did not occur in the Oldman River in 1988.

The present water balance model simulation (OD05) is evaluated as providing conditions which are better than both the recorded and natural flow regimes over the period of record for brown trout, rainbow trout, walleye and sauger. The water balance model is presently being reprogrammed to accept the streamflow recommendations provided by the Fish Rule Curve. The potential does therefore exist for further improvements in habitat availability for the target species over the natural and recorded flow regimes. Gains or losses in habitat with future water balance model runs will only be apparent, however, after the model output is analyzed.

This analysis is subject to several qualifications, one of which is the fact that cover is essentially nonexistent for the trout species downstream of the damsite. This cover may be created (see Appendix III); therefore, the extent to which the riverine environment is suitable for use by the trout species will depend in part on the effort expended in creating these cover types.

The target species in the coldwater section of the river were identified as brown and rainbow trout. At present, these species occur very sporadically in the downstream region of the river (Fernet and Matkowski 1986a, 1986b). Rainbow trout juveniles

do make limited use of this region of the river for rearing. The rainbow trout juvenile and adult life stages also overwinter downstream of the damsite. The spawning and fry life stages have not been identified in this region of the Oldman River, and use by the adult life stage during the open-water season is relatively rare.

The issue of rainbow trout spawning downstream of the damsite had been previously examined (Fernet and Matkowski 1986b), and although suitable spawning areas had been noted, no spawning activity was detected. The results of examining water temperatures during the spawning and incubation life stages (HydroQual 1990) has provided some insight into this apparent lack of habitat use. Between 1982 and 1986, on one occasion only (1986) was the thermal regime judged suitable for spawning use by rainbow trout downstream of the proposed damsite (i.e., seven consecutive days during which the daily minima equalled or exceeded 5°C and the daily maxima was 10°C or less). In 1986, the criteria established for successful egg incubation was not met (i.e., 320 degree days when the daily minima equalled or exceeded 7°C and the daily maxima was 14°C or less). Thus it appears the thermal regime downstream of the damsite is inappropriate for successful rainbow trout spawning.

With the reservoir in place, thermal simulations indicate there would only be a slight improvement in this situation, with successful rainbow trout spawning and incubation occurring in one year (1985) of the five-year period examined (HydroQual 1990). In addition, the appropriate thermal conditions were only noted below the damsite, and did not persist as far downstream as LNID. The poor frequency of suitable rainbow trout spawning and incubation temperatures indicates that either suitable mitigation measures must be developed to provide appropriate spawning and incubation characteristics, or stocking would have to be pursued to provide a standing stock of this species downstream of the damsite.

The estimated thermal regime of reservoir releases during the 1982 to 1986 period would have provided suitable temperatures for the fry, juvenile and adult life stages of rainbow trout at least as far downstream as the confluences with the Belly River. However, in addition to the inherent lack of cover for these life stages, there is also a shortage of areas providing suitable depths and velocities for the rainbow trout fry and juvenile life stages. As is the case with cover, these habitat characteristics may be created (Appendix III). The extent to which suitable habitat for these life stages exists will depend on the quantity of these habitat types which is created.

The examination of the thermal regime in the context of requirements for brown trout provided some very encouraging results. Suitable spawning and incubation temperatures downstream of reservoirs releases were identified in each of the five years examined from the damsite downstream to Fort Macleod and for one year (upstream Belly) to four years (Lethbridge, Fincastle) out of five in the downstream area of the river. An additional issue was identified near the damsite, however, which was the potential for premature maturation, hatching and emergence of brown trout fry. This consequence was attributed to the relatively warm (i.e., 4°C) reservoir releases during the incubation period. This issue will have to be addressed in mitigation planning.

The thermal regime as estimated from water balance model simulations is also very suitable for brown trout fry, juvenile and adult life stages throughout the Study Area (i.e., not only the coldwater but also the coolwater region). The provision of appropriate flows alone will not facilitate the development of a brown trout fishery, however. Cover will have to be created for the fry, juvenile and adult life stages. Other limiting habitat features (e.g., suitable depths and velocities for the immature stages) have been identified, and designs developed to provide these habitat features within the flow regime which will be

experienced (Appendix III). The degree to which the downstream segments of the river provide these habitat types will depend on the extent of habitat enhancement activities.

The thermal regime for walleye [and sauger by inference as their temperature requirements and preferences are similar (Scott and Crossman 1973)] is suitable downstream of Fort Macleod, based on analysis of water balance model output (HydroQual 1990).

## 7.2 EFFECTS OF FLOW REGULATION ON HABITAT AVAILABILITY

The 'composite' fish was created, and the habitat duration analysis carried out to evaluate the impacts of flow regulation on the target species.

As noted, this analysis was based on the assumption that all required habitat features (e.g., cover for the trout species) had been created as a component of the mitigation plan. This analysis indicated increases in the measure of habitat availability employed for the 'composite' fish in all river segments except 6, with the OD05 simulation. These increases are considered to be representative of the gains in habitat which will occur for the target species. Subsequent water balance model simulations which incorporate the Fish Rule Curve flow recommendations are anticipated to equal or exceed the habitat gains reported here.

## 8.0 REFERENCES CITED

Bovee, K.D. 1982. A guide to stream habitat analysis using the Instream Flow Incremental Methodology. Instream Flow Information Paper No. 12. Cooperative Instream Flow Service Group, USDI, WELUT, Office of Biological Services. FWS/OBS-8/26. 248 pp.

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the Instream Flow Incremental Methodology. Instream Flow Information Paper No. 21. U.S. Fish and Wildlife Service, Biol. Rep. 86 (7). 235 pp.

Bovee, K.D. and R. Milhous. 1978. Hydraulic simulation in instream flow studies, theory and techniques. Instream Flow Information Paper No. 5. Cooperative Instream Flow Service Group, USDI, WELUT, Office of Biological Services. FWS/OBS-78/33. 129 pp.

Cherlak, E.F. and J.C. Garcia. 1988. An evaluation of the effects of various smoothing and curve-fitting techniques on the accuracy of suitability functions. In: K. Bovee and J.R. Zuboy (eds.). Proc. Workshop on the Development and Evaluation of Habitat Suitability Criteria. Colorado State University, Fort Collings, CO. pp. 259-283.

Colby, P.J., R.E. McNicol and R.A. Rycker. 1979. Synopsis of biological data on the walleye, Stizostedion v. vitreum (Mitchill 1818). FAO Fish. Synop., 119. 139 pp.

Crance, J.H. 1986. Sauger habitat suitability index curves developed by the Delphi technique. Instream Flow and Aquatic Systems Group, Fort Collins, Colorado. 34 pp.

Fernet, D.A. and G.L. Walder. 1986. The development of habitat suitability criteria for use with the Instream Flow Incremental Methodology, a manual for the Province of Alberta. Prepared for Habitat Branch, Fish and Wildlife Division. 141 pp.

Fernet, D.A. and S.M. Matkowski. 1986a. Oldman River Dam environmental mitigation/opportunities plan instream flow study. Fish distribution, abundance, critical habitats and relationships with streamflow downstream of the Oldman River Damsite. Prepared for Planning Division, Alberta Environment. 137+ pp.

Fernet, D.A. and S.M. Matkowski. 1986b. Distribution, abundance and habitat utilization of sport fishes downstream of the Oldman River Damsite, late winter and spring, 1986. Prepared for Planning Division, Alberta Environment. 50+ pp.

Fernet, D.A. and S.M. Matkowski. 1986c. Instream flow needs of fishes in Pekisko and Stimson creeks. Prepared for Planning Division, Alberta Environment. 26+ pp.

Fernet, D.A. and S.M. Matkowski. 1987. Relationships between habitat availability and discharge for selected fish species downstream of the proposed Oldman River Dam. Prepared for Planning Division, Alberta Environment. 59 pp.

Geer, W.H. 1987. A method for treatment of data from the Instream Flow Incremental Methodology for instream flow determination. Pages 1-25 In: J.F. Craig and J.B. Kemper, editors. Regulated Streams Advances in Ecology. Plenum Press, New York.

HydroQual Consultants Inc. 1990. Data summary on Oldman River water quality projections. Prepared for Planning Division, Alberta Environment. 160 pp.

J.N. MacKenzie Engineering Ltd. 1989. Oldman River Dam downstream fisheries habitat mitigation data summary (Draft). Prepared for Environmental Management Associates.

Jackle, M.D. and P.J. Barrett. 1988. A statistical approach to determining sample size for species habitat preference curves. In: Proceedings of a workshop on the development and evaluation of habitat suitability criteria. K. Bovee and J.R. Zuboy, (eds.). U.S. Dept. of Interior. Fish and Wildlife Service. Research and Development. Washington, D.C. 20240.

Locke, A.G.H. 1988. Sheep River instream flow needs study. Fish and Wildlife Division, Alberta Forestry, Lands and Wildlife. 143 pp.

McElhanney Group Ltd. 1985. Ground survey results for study sites along Oldman River, southern Alberta. Prepared for Environmental Management Associates.

McMahon, T.E., J.W. Terrell and P.C. Nelson. 1984. Habitat suitability information: walleye. U.S. Fish and Wildlife Service. FWS/OBS-82/10.56. 43 pp.

Milhous, R.T., D.L. Wegner and T. Waddle. 1984. User's guide to the Physical Habitat Simulation System (PHABSIM). Instream Flow Information Paper No. 11. Fish and Wildlife Service, USDI, Washington, D.C. FWS/OBS-81/43, Revised.

Nelson, W.R. 1968. Embryo and larval characteristics of sauger, walleye and their reciprocal hybrids. Trans. Amer. Fish. Soc. 97 (2): 167-174.

Norden, C.R. 1961. The identification of larval yellow perch, Perca flavescens and walleye, Stizostedion vitreum. Copeia 1961 (3): 282-288.

O'Neil, J. and L. Hildebrand. 1986. Fisheries resources upstream of the Oldman River Dam. Prepared for Planning Division, Alberta Environment, Edmonton. 131 pp.

Paetz, M.J. and J.S. Nelson. 1970. The Fishes of Alberta. The Queens Printer, Edmonton. 282 pp.

Raleigh, R.F., T. Hickman, R.C. Solomon and P.C. Nelson. 1984. Habitat suitability information: rainbow trout. U.S. Fish and Wildlife Service. FWS/OBS-82/10.60. 64 pp.

Raleigh, R.F., L.D. Zuckerman and P.C. Nelson. 1986. Habitat suitability index models and instream flow suitability curves: brown trout, revised. U.S. Fish and Wildlife Service. Biol. Rep. 82 (10.124). 65 pp. [First printed as: FWS/OBS-82/10.71, September 1984].

Reiser, D.W., M.P. Ramey and T.R. Lambert. 1985. Review of flushing flow requirements in regulated streams. Pacific Gas and Electric Company. San Ramon, California. 97+ pp.

Sale, M.J., S.F. Railsback and E.E. Herricks. 1981. Frequency analysis of aquatic habitat: a procedure for determining instream flow needs. Pages 340 - 346 In: Acquisition and Utilization of Aquatic Habitat Inventory Information, Proc. Symposium held 28-30 October, 1981. Portland, Oregon, Western Division, Am. Fish. Soc.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada, Ottawa. Bulletin 184. 966 pp.

Sosiak, A.J. 1983. Elbow and Bow River brown trout spawning surveys, fall 1982. Unpublished Report. Alberta Energy and Natural Resources, Fish and Wildlife Division, Calgary. 33 pp.

Terzi, R.A. 1981. Hydrometric field manual-measurement of streamflow. Environment Canada, Inland Waters Directorate, Water Resources Branch, Ottawa. 37 pp.

Trihey, E.W. and D.L. Wegner. 1981. Field data collection procedures for use with the Physical Habitat Simulation System of the Instream Flow Group. Partial revision in February, 1983. Draft Report. Cooperative Instream Flow Service Group, Fort Collins, Colorado. 131 pp.

Wiebe, A.P. and R.D. Konynenbelt. 1980. Spawning survey, habitat utilization and fish distribution, Bow River, 1980. Unpublished Report. Alberta Energy and Natural Resources, Fish and Wildlife Division, Calgary. 103 pp.

# APPENDIX I

## AN EXAMINATION OF THE TRANSFERABILITY OF HABITAT PREFERENCE CRITERIA, RAINBOW TROUT AND BROWN TROUT

# AN EXAMINATION OF THE TRANSFERABILITY OF HABITAT PREFERENCE CRITERIA

## RAINBOW TROUT AND BROWN TROUT

## DATA REPORT

Prepared for:

Alberta Public Works, Supply and Services
Oldman River Dam Project
Edmonton, Alberta

Prepared by:

Environmental Management Associates
Calgary, Alberta

AND

R.L. & L. Environmental Services Ltd.
Edmonton, Alberta

March, 1989

# TABLE OF CONTENTS

PAGE

TABLE OF CONTENTS ..... i

LIST OF FIGURES ..... ii

LIST OF TABLES ..... iv

1.0 INTRODUCTION ..... 1

2.0 METHODS ..... 3

2.1 STUDY AREAS ..... 3
2.2 HABITAT AVAILABILITY DATA ..... 3
2.3 HABITAT UTILIZATION DATA ..... 5
2.4 HABITAT PREFERENCE CRITERIA ..... 9
2.5 TRANSFERABILITY ANALYSIS ..... 10

3.0 RESULTS ..... 12

3.1 IFN DATA ..... 12
3.2 BIOLOGICAL PREFERENCE CURVES ..... 12

4.0 DISCUSSION AND CONCLUSION ..... 33

5.0 REFERENCES CITED ..... 36

APPENDIX I RAINBOW TROUT UTILIZATION, AVAILABILITY AND PREFERENCE CRITERIA

## LIST OF FIGURES


| | | PAGE |
|---|---|---|
| FIGURE 1 | LOCATION OF CROWSNEST RIVER STUDY REACH, 1989 ..... | 4 |
| FIGURE 2 | PREFERENCE AND TRANSFERABILITY DATA, RAINBOW TROUT FRY ..... | 15 |
| FIGURE 3 | PREDICTED AND OBSERVED DEPTH AND VELOCITY CRITERIA, RAINBOW TROUT FRY, CROWSNEST RIVER REACH 3 ..... | 16 |
| FIGURE 4 | COMPARISON OF DEPTH AND VELOCITY DISTRIBUTIONS, RAINBOW TROUT FRY, CROWSNEST RIVER ..... | 18 |
| FIGURE 5 | PREDICTED AND OBSERVED SUBSTRATE AND COVER CRITERIA, RAINBOW TROUT FRY, CROWSNEST RIVER REACH 3 ..... | 19 |
| FIGURE 6 | COMPARISON OF SUBSTRATE AND COVER DISTRIBUTIONS, RAINBOW TROUT FRY, CROWSNEST RIVER ..... | 20 |
| FIGURE 7 | PREFERENCE AND TRANSFERABILITY DATA, RAINBOW TROUT JUVENILES ..... | 22 |
| FIGURE 8 | PREFERENCE AND TRANSFERABILITY DATA, RAINBOW TROUT ADULTS ..... | 23 |
| FIGURE 9 | PREDICTED AND OBSERVED DEPTH UTILIZATION, RAINBOW TROUT ADULTS, CROWSNEST RIVER REACH 3 ..... | 24 |
| FIGURE 10 | PREDICTED AND OBSERVED COVER UTILIZATION, RAINBOW TROUT ADULTS, CROWSNEST RIVER REACH 3 ..... | 24 |
| FIGURE 11 | COMPARISON OF COVER DISTRIBUTIONS, RAINBOW TROUT ADULTS, CROWSNEST RIVER ..... | 24 |
| FIGURE 12 | PREFERENCE AND TRANSFERABILITY DATA, RAINBOW TROUT SPAWNING ..... | 26 |
| FIGURE 13 | PREFERENCE AND TRANSFERABILITY DATA, BROWN TROUT FRY ..... | 27 |
| FIGURE 14 | COMPARISON OF DEPTH DISTRIBUTIONS, BROWN TROUT FRY, CROWSNEST AND BOW RIVERS ..... | 28 |

## LIST OF FIGURES (Concluded ...)

FIGURE 15 PREFERENCE AND TRANSFERABILITY DATA, BROWN TROUT JUVENILES ..... 29

FIGURE 16 PREFERENCE AND TRANSFERABILITY DATA, BROWN TROUT ADULTS ..... 31

FIGURE 17 PREFERENCE AND TRANSFERABILITY DATA, BROWN TROUT SPAWNING ..... 32

## LIST OF TABLES


| | | PAGE |
|---|---|---|
| TABLE 1 | SUBSTRATE DEFINITIONS AND SIZE-RANGE CATEGORIES ..... | 6 |
| TABLE 2 | COVER-TYPE CODINGS, DEFINITIONS AND FUNCTIONS ..... | 7 |
| TABLE 3 | SUMMARY OF FIELD MEASUREMENTS AT THE CROWSNEST RIVER, REACHES 2 AND 3, APRIL TO NOVEMBER, 1988 ..... | 8 |
| TABLE 4 | NUMBER OF HABITAT UTILIZATION DATA POINTS FOR TRANSFERABILITY ANALYSIS, REACHES 1, 2 AND 3 OF THE CROWSNEST RIVER ..... | 13 |
| TABLE 5 | COMPARISON OF HISTORIC CROWSNEST RIVER DISCHARGE RATES WITH THOSE EXPERIENCED IN 1988 ..... | 34 |

## 1.0 INTRODUCTION

The Oldman River Dam Project Office of Alberta Public Works, Supply and Services is in the process of examining the issues of instream flow needs (IFN) for the fish fauna of the Oldman River downstream of the damsite. This report addresses one component of the study, which is an assessment of the transferability of fish habitat preference criteria to the Oldman River.

The IFN study was undertaken to examine the requirements of priority management species in the Oldman River (Fernet et al. 1989). These species included rainbow trout (Onchorhynchus mykiss) and brown trout (Salmo trutta). Since most life stages of both species were rarely, if ever, found downstream of the damsite on the Oldman River (other than rainbow trout juveniles), estimates could not be made of their habitat requirements or preferences. Therefore, in order to obtain this habitat preference information, estimates were based on studies in rivers where these species were known to occur. Rainbow trout information was gathered from studies in the Crowsnest River, downstream of Lundbreck Falls, while brown trout information was obtained from the Bow River (Fernet et al. 1989). The applicability or transferability of this information to the Oldman River therefore required evaluation.

The estimates for rainbow trout habitat preferences from the Crowsnest River downstream of Lundbreck Falls were considered transferable. This was due to the fact that the Crowsnest is a tributary of the Oldman River and the rainbow trout in the lower Crowsnest River were thought to be the same population as that in the Oldman River. The transferability of these data were examined as a test of the quality of the habitat preferences which were defined. The transferability of the brown trout habitat information from the Bow River to the Oldman River did, however, require examination.

The present study was designed to examine the transferability of habitat preference data for the various life stages of rainbow trout (exclusive of juveniles) and brown trout to the Oldman River.

# 2.0 METHODS

## 2.1 STUDY AREAS

Two study reaches were created on the Crowsnest River in 1988 to test the transferability of the source stream preference curves. The rationale for selecting the study reaches in the Crowsnest River was due to the low numbers and limited utilization of rainbow trout and brown trout in the mainstream Oldman River (i.e., no known spawning areas for brown trout; very limited use of the Oldman River by rainbow trout for spawning). An attempt was made to choose areas which supported all life stages of the target species (i.e., adult, juvenile, fry and spawning) and provided a wide diversity of available habitats.

Study reaches were established in the lower section of the Crowsnest River (Figure 1). The study reaches were numbered Reach 2 and Reach 3 to distinguish them from the source reach for rainbow trout, known as Reach 1. Study Reach 2, located immediately upstream of Reach 1 (Figure 1), provided brown trout information to compare with that obtained from the Bow River. Reach 3, located upstream of Lundbreck Falls (Figure 1), contained a population of rainbow trout which was isolated from the Reach 1 population by the presence of Lundbreck Falls. The rainbow trout population in Reach 3 was therefore used to generate preference criteria which were employed to test the transferability of the preference curves previously developed from Reach 1 (Fernet et al. 1989).

## 2.2 HABITAT AVAILABILITY DATA

Study Reaches 2 and 3 on the Crowsnest River were visited in the spring of 1988 by Environmental Management Associates (EMA), R.L. & L. Environmental Services Ltd. (R.L. & L.), and Fish and

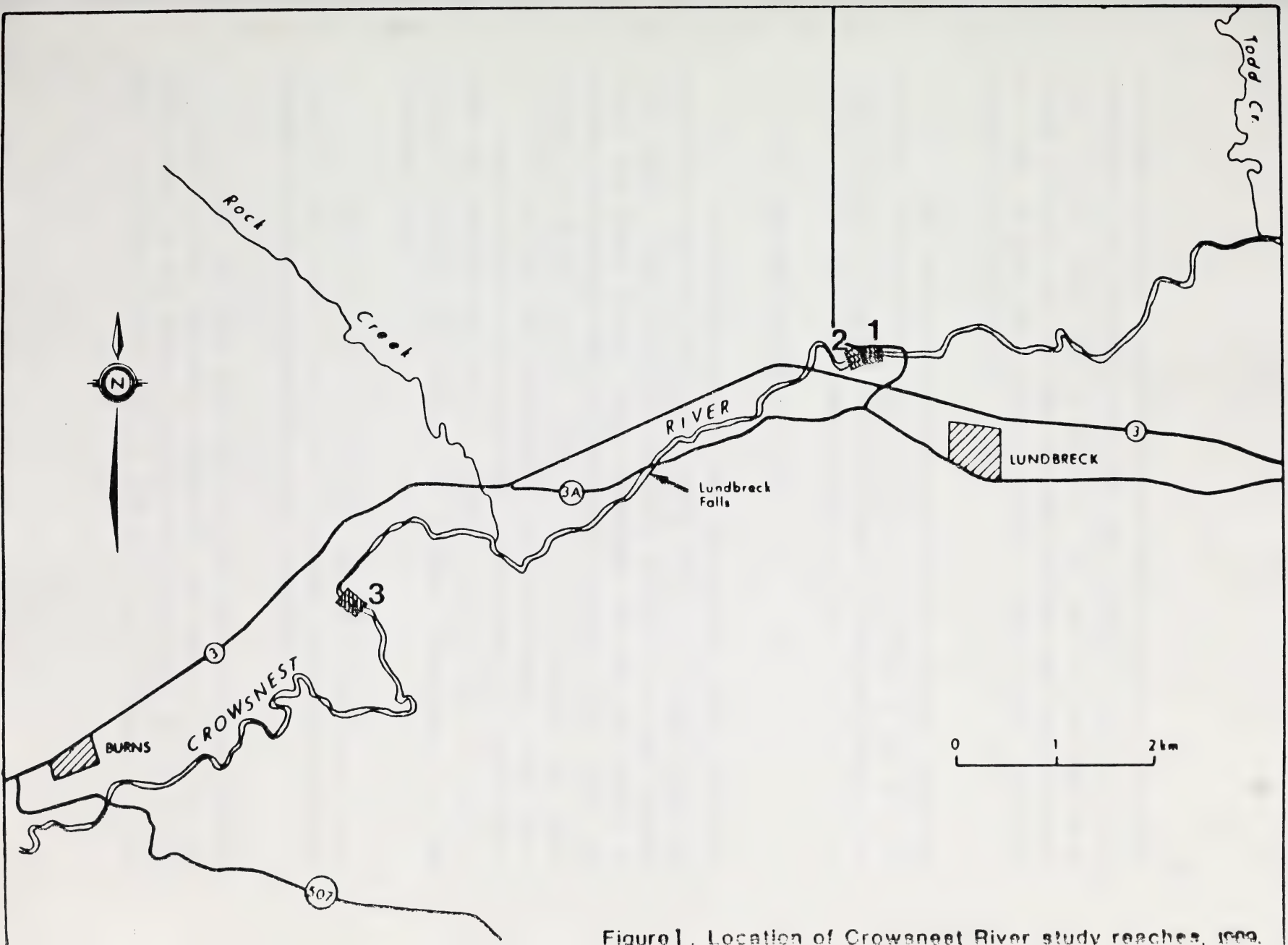



Figure 1. Location of Crowsnest River study reaches, 1989.

Wildlife Division personnel who established transects on each reach and marked each transect with permanent headpins. The techniques used for the collection of hydraulic and habitat information at study transects and the data recorded followed the specifications for use of the IFG4 hydraulic model (Bovee 1982), which is summarized by Fernet et al. (1989).

The coding criteria and definitions used for substrate and cover categorization are presented in Tables 1 and 2. The dates on which hydraulic and habitat measurement were made at both study reaches are summarized in Table 3.

## 2.3 HABITAT UTILIZATION DATA

Microhabitat utilization data (velocity, depth, substrate and cover) from each of the two study areas was collected for all life stages (fry, juvenile, adult and spawning) of both rainbow trout and brown trout. All techniques for the collection of habitat utilization data are discussed in Fernet et al. (1989) and Fernet and Walder (1986). Brown trout fry, juvenile and adult observations were taken from Reach 2 on 8 to 13 August, 1988 (Table 3). Due to the low numbers of brown trout in Reach 2, observations were also made for fry (9 to 10 August), juvenile (12 to 13 July), adults (8 August) and spawning (10 November) from Reach 1 of the Crowsnest River.

Rainbow trout fry, juvenile and adult observations were obtained from Reach 3 on 11 to 12 August, while the spawning observations were obtained on 27 April (Table 3).

The strategy employed in the collection of habitat utilization data involved attempting to observe all of the individuals of the target species within the study reach (Bovee 1986). All brown trout juvenile and adult, and virtually all fry

**TABLE 1**

**SUBSTRATE DEFINITIONS AND SIZE-RANGE CATEGORIES**

| CODE | CLASS NAME | SIZE RANGE mm | SIZE RANGE INCHES |
|---|---|---|---|
| 1 | Clay/Silt | <0.062 | <0.0024 |
| 2 | Sand | 0.062-2.0 | 0.0024-0.08 |
| 3 | Small Gravel | 2-8 | 0.08-0.03 |
| 4 | Medium Gravel | 8-32 | 0.03-1.3 |
| 5 | Large Gravel | 32-64 | 1.3-2.5 |
| 6 | Small Cobble | 64-128 | 2.5-5 |
| 7 | Large Cobble | 128-256 | 5-10 |
| 8 | Small Boulder | 256-762 | 10-30 |
| 9 | Large Boulder | >762 | >30 |
| 10 | Bedrock | | |

**TABLE 2**

**COVER-TYPE CODINGS, DEFINITIONS AND FUNCTIONS**

| CODE | TYPE | FUNCTION | EXAMPLES |
|---|---|---|---|
| 1 | No cover | No cover | No cover, deep pool |
| 2 | Instream object | Velocity shelter | Boulders, partially buried logs, bedrock ledges |
| 22 | Instream object, edge effect | | |
| 3 | Instream overhead | Direct visual isolation | Undercut bank, log jams, surface turbulence, deep pools |
| 33 | Instream overhead, edge effect | | |
| 4 | Offstream overhead | Indirect visual isolation | Overhanging canopy |
| 44 | Offstream overhead, edge effect | | |
| 5 | Combination object and overhead | Combination velocity shelter and visual isolation | Root wads, brush piles, emergent vegetation, compact log jams, any super-imposed object with overhead cover |
| 55 | Combination object and overhead, edge effect | | |

TABLE 3

SUMMARY OF FIELD MEASUREMENTS AT THE CROWSNEST RIVER
REACHES 2 AND 3, APRIL TO NOVEMBER, 1988

| | REACH 2 | | REACH 3 | |
|---|---|---|---|---|
| DATE, 1988 | ACTIVITY[a] | DISCHARGE ($m^3/s$)[b] | ACTIVITY | DISCHARGE ($m^3/s$) |
| 26-27 April | - Complete hydraulic survey<br>- Habitat availability measurements | 3.85 | - Complete hydrualic survey<br>- Habitat availability measurements<br>- Spawning rainbow trout habitat utilization observations | 4.15 |
| 26-27 May | - Hydraulic survey | 9.51 | - Hydraulic survey | 9.87 |
| 5-12 July | - Brown trout habitat utilization observations | 4.36 | | |
| 8-11 August | - Brown trout habitat utilization observations | 2.70 | | |
| 11-12 August | - | | - Rainbow trout habitat utilization observations | 2.55 |
| 10 October | - Brown trout spawning habitat observations | 2.32 | | |

a Complete hydraulic survey = distributions of depths and velocities at all transects and determination of water surface elevations.
hydraulic survey = as above, except no determinations of water surface elevations.

b Discharge presented for 1st day of study trip.

present in reaches 1 and 2 of the Crowsnest River were recorded on the sampling dates, while all redds present in the study reaches were recorded during the spawning period. All rainbow trout redds constructed in Reach 3 were recorded during the study, while all adults and virtually all the fry which were present on 11 and 12 August were included in the study. The examination of juvenile rainbow trout habitat preferences was not within the Terms of Reference for the study. However, habitat utilization information for 68 juvenile rainbow trout was collected in Reach 3, which represented only a small component of numbers of juveniles present in the study reach. Juvenile rainbow trout was the only life stage of either of the target species which was abundant in the Crowsnest River study areas.

## 2.4 HABITAT PREFERENCE CRITERIA

The methods used to develop the habitat preference curves, as discussed by Bovee (1986) and Fernet and Walder (1986), involve a frequency analysis of used and available habitat characteristics. It was anticipated that a frequency distribution for each habitat characteristic under study (depth, velocity, substrate and cover) could be calculated for each life stage of each species for both of the study reaches. However, there were an insufficient number of individuals present in the study reaches for all life stages of brown trout and spawning rainbow trout to enable this type of analysis. These life stages were treated in a different manner, which is discussed separately.

Frequency distributions of habitat utilization and habitat availability data were created for the rainbow trout fry, juvenile and adult life stages. The utilization and availability data were organized into normalized histograms. A preference curve was then generated by dividing the habitat utilization histogram by the habitat availability histogram for each parameter under

study (Fernet and Walder 1986). The result is a preference or suitability curve for the species in the stream under study.

## 2.5 TRANSFERABILITY ANALYSIS

In order to assess the transferability of source stream preference curves, the preference criteria generated for rainbow trout (Reach 3) and brown trout (Reach 1 and 2) were superimposed onto the suitability curves from the source streams. This technique is known as abbreviated convergence analysis (Bovee 1986).

Although only a small number of observations ($\leq$25) are required for abbreviated convergence analysis, the number of brown trout observations and rainbow trout spawning observations were insufficient to enable such a comparison. The measurements for each of the four parameters under study (depth, velocity, substrate and cover) for each observation were therefore superimposed on the suitability curves from the source stream. If these observations were subsets of the suitability curves generated from the source streams, a high degree of correlation would be anticipated. A positive correlation would support the hypothesis that the source stream suitability curves were truly preference curves for the species regardless of location, and thus would be transferable to other streams.

Where the abbreviated convergence analysis was employed, if any inconsistencies occurred (i.e., if the rainbow trout curves from the study reach did not fall within the suitability curves from the source stream), the actual habitat utilization data for the study stream was compared to the predicted utilization curve developed for the study stream using the technique described by Kinzie and Ford (1988). The method involves the creation of a predicted utilization function for a study stream using the

availability function for that study site in combination with the preference function from a source stream. The use of goodness of fit statistics is not possible in comparing the preference functions from the two streams since the preference curve for each variable at each study site is correlated with the microhabitat availability at that site (Kinzie and Ford 1988).

A predicted utilization function for the study reach in question is generated by multiplying the preference from the source stream by the habitat availability of the study site. This technique assumes that, given the availability restrictions of the study stream, the source stream utilizations and therefore preferences should be comparable to those of the study stream.

The predicted utilization function was therefore compared with the observed utilization. If there were no observable differences, the preference information from the source stream was considered to have predicted the distribution of fish in the study stream, and the source stream habitat preference criteria were considered transferable. If differences were observed between the predicted utilization function and the habitat preference identified, there was insufficient evidence to support the hypothesis that the source stream suitability curve was transferable for the variable in question.

# 3.0 RESULTS

## 3.1 IFN DATA

The dates on which measurements were conducted at Reaches 2 and 3 on the Crowsnest River and, where applicable, the calculated discharges for these sampling dates are summarized on Table 3. Utilization data was not obtained at discharges greater or less than those at which the availability could be calculated with a high degree of confidence. Habitat availability can be modelled to represent conditions at the discharges at which observations were taken. The methods for obtaining and analyzing habitat availability are outlined in Bovee (1986) and Fernet and Walder (1986).

## 3.2 BIOLOGICAL PREFERENCE CURVES

The number of observations for which measurements of microhabitat data were obtained for each life stage of the two trout species is summarized in Table 4.

As discussed in Section 2.3, the sampling strategy employed involved documentation of habitat use by all individuals of all life stages of the target species within the respective study areas. This undertaking was successful, with the exception of the rainbow trout juveniles life stage, which was specifically excluded from the Terms of Reference for the study. However, possibly due to the exceptionally low discharges experienced in the Crowsnest River in 1988, the number of individuals present (with the exception of rainbow trout juveniles) was much fewer than anticipated.

Bovee (1986) suggests that a minimum of 25 data points is necessary to produce a preference curve for transferability

**TABLE 4**

**NUMBER OF HABITAT UTILIZATION DATA POINTS FOR TRANSFERABILITY ANALYSIS, REACHES 1, 2 AND 3 OF THE CROWSNEST RIVER**

| SPECIES | LIFE STAGE | NUMBER OF OBSERVATIONS |
|---|---|---|
| Rainbow trout (Reach 3) | Fry | 17 |
| | Juvenile | 68 |
| | Adult | 23 |
| | Spawning | 9 |
| Brown trout (Reaches 1 & 2) | Fry | 7 |
| | Juvenile | 6 |
| | Adult | 2 |
| | Spawning | 3 |

analysis. Due to the small numbers of certain life stages present, the criterion employed in the present study for development of transferability preference curves was 15. Sufficient numbers of adults, juvenile and fry rainbow trout were obtained using the criterion of 15 data points (Table 4). The rainbow trout utilization, availability and preference curves which were designed in this manner are presented in Appendix I.

Only nine data points were obtained in Reach 3 for spawning rainbow trout in April of 1988 (Table 4). The problem of insufficient data points occurred for all life stages of brown trout in Reaches 1 and 2 of the Crowsnest River (Table 4). Therefore, as discussed in Section 2.5, the individual observations were superimposed onto the suitability curves of the source streams. This was deemed the best available test of data transferability.

Rainbow Trout Fry

The various habitat preference curves generated for rainbow trout fry (Figure 2) in study Reach 3 were slightly different from those of the source stream. The depth and velocity transferability data suggested a slight preference for depths and velocities greater than those expressed by the source stream preference curve. The difference justified the development of predicted utilization curves, which are compared with the observed utilization curves in Figure 3.

Given the source stream preference criteria, rainbow trout fry were not predicted to use depths or velocities as great as those in the study reach. The discrepancy suggested a difference in habitat availabilities in the two study areas. However, examination of the complete range of availabilities for these parameters in both the source stream and the study reach

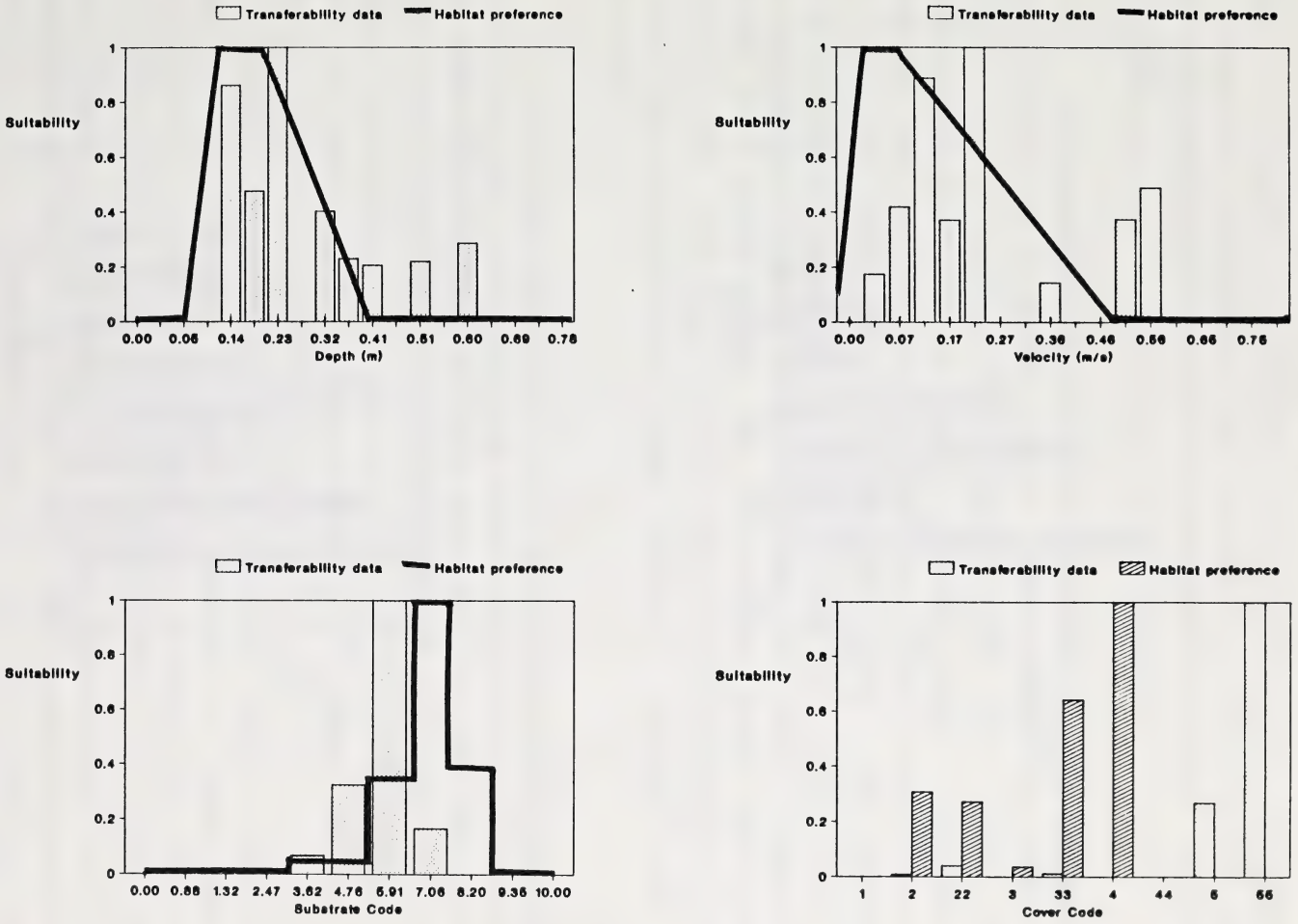
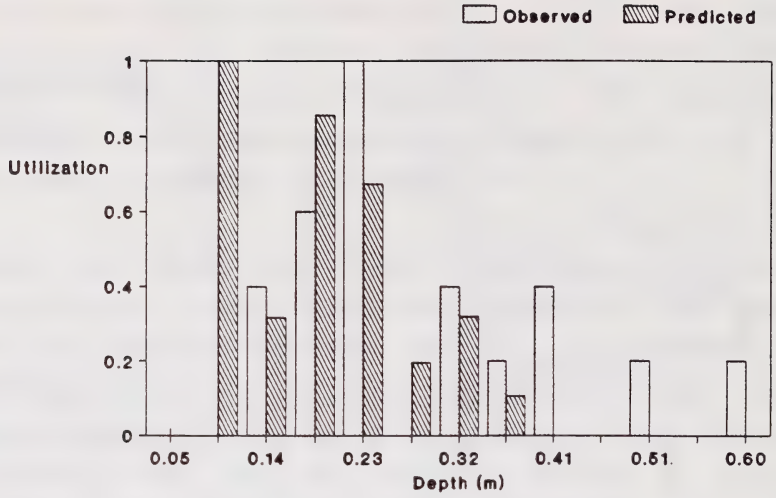



Figure 2. Preference and transferability data, rainbow trout fry.



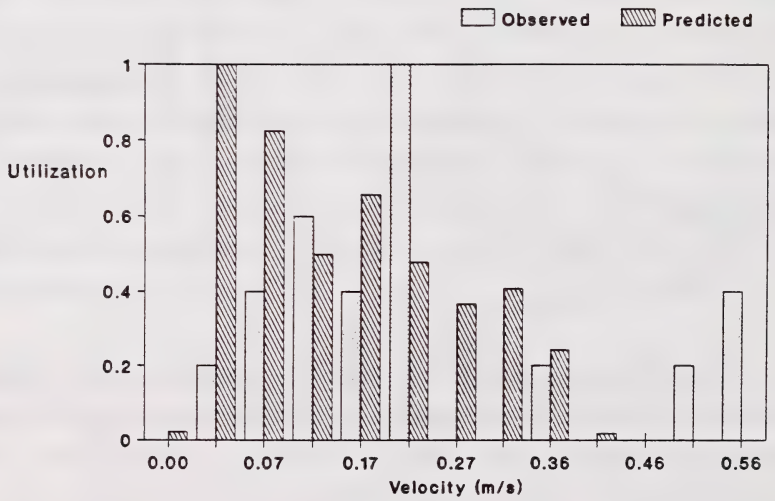
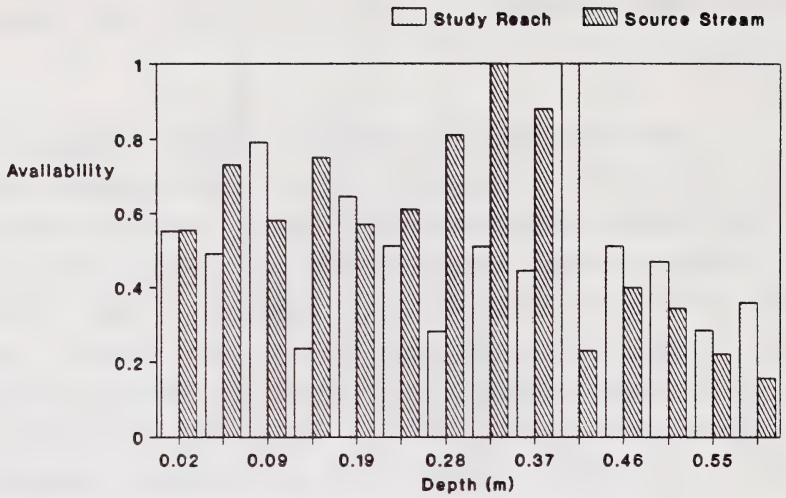




Figure 3. Predicted and observed depth and velocity criteria, rainbow trout fry, Crowsnest River Reach 3.

(Figure 4) suggested that habitat was not limiting. Therefore, to be universally transferable, the suitability curve of the source stream should include a slight preference for greater depths and velocities.

The substrate suitability curves (Figure 2) indicate the rainbow trout fry in Reach 3 (i.e., transferability study site) have the highest preference for small cobble, while those of the source stream prefer large cobble. However, all of the substrate values in the transferability data set fall within the range created by the source stream suitability curve. The development of the predicted utilization curves (Figure 5) indicate that it is the limited availability of the substrate in Reach 3 (Appendix I, Figures 1-3) which shifts the preference toward the smaller substrate size. The comparison of substrate distribution in Reach 3 with that of the source stream (Figure 6) substantiates this conclusion.

The comparison of the cover suitability criterion (Figure 2) also indicated that the study reach fish have a preference for some cover types which were not suggested by the source stream data. The predicted and observed cover preference data are compared in Figure 5. The use of all cover types other than Types 5 and 55 (combination instream overhead and object and its edge effects) indicate reasonable correlations. The lack of predicted utilization for cover Types 5 and 55 suggest a lack of these cover types in the source stream. However, a comparison of availabilities (Figure 6) indicated that, although limited in some cases, all cover types were present in both the study reach and the source stream. This suggests that perhaps there should be a slight change made to the source stream suitability curve to include the preference for these cover types, in the development of highly transferable data.



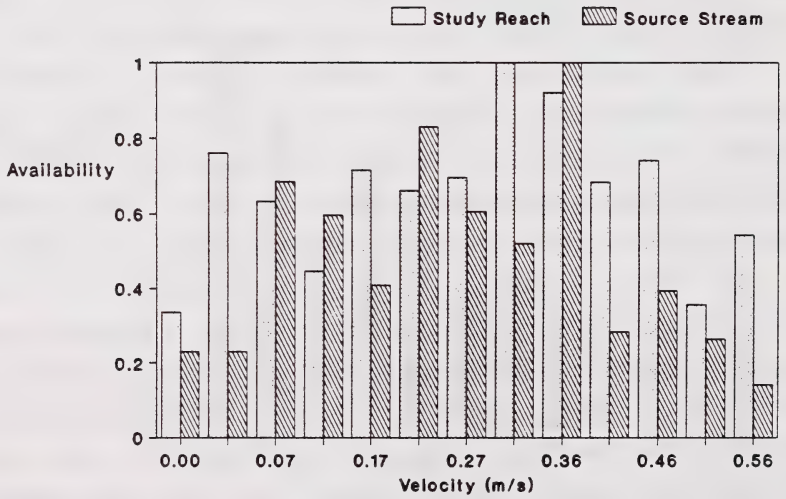




Figure 4. Comparison of depth and velocity distributions, rainbow trout fry, Crowsnest River.

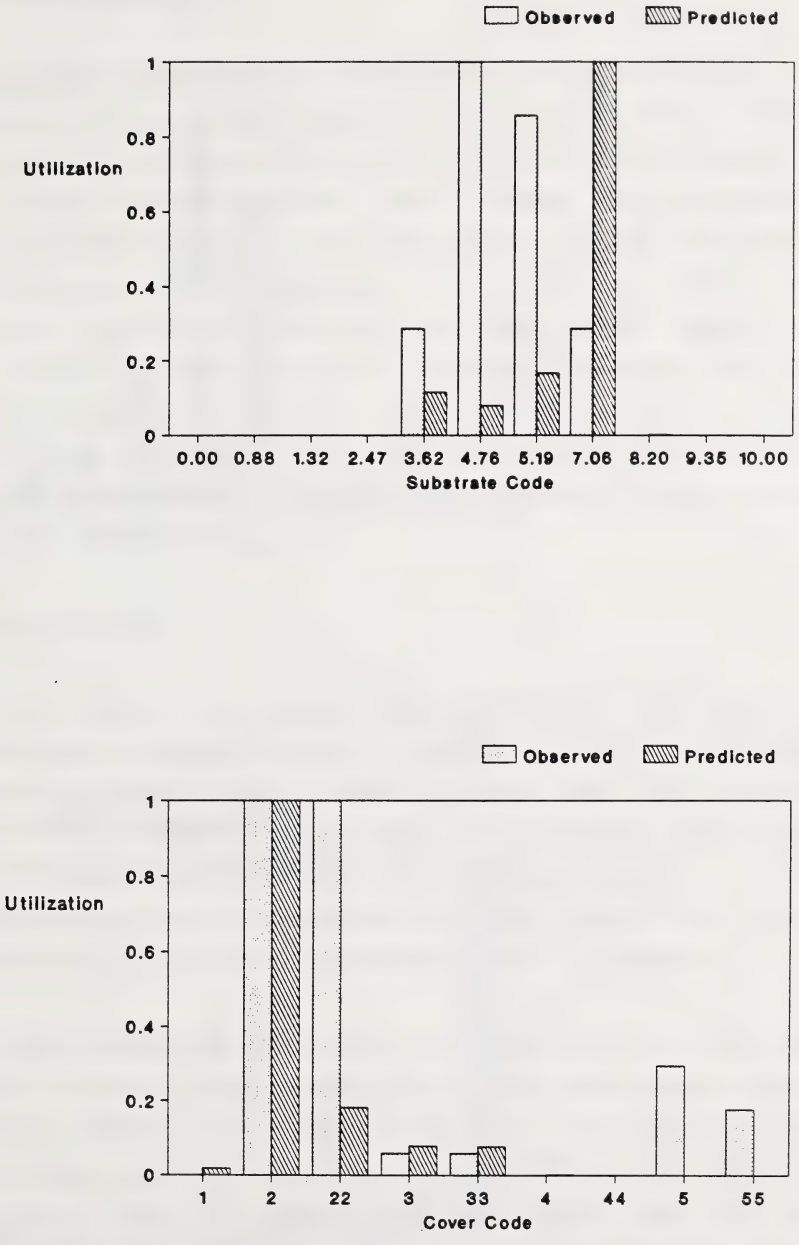
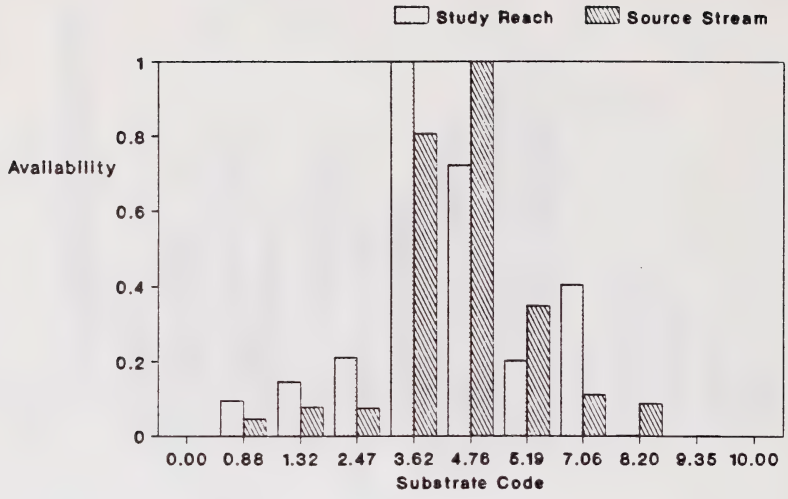



Figure 5. Predicted and observed substrate and cover criteria, rainbow trout fry, Crowsnest River Reach 3.



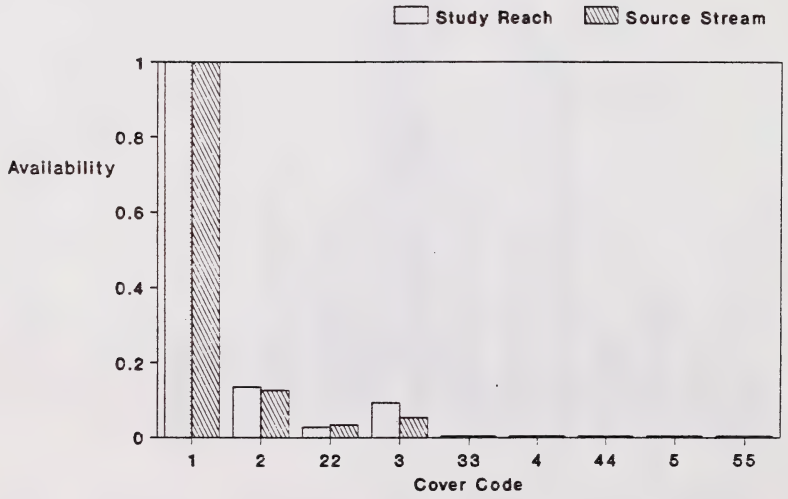




Figure 6. Comparison of substrate and cover distributions, rainbow trout fry, Crowsnest River.

Rainbow Trout Juvenile

The source stream information for rainbow trout juveniles was developed in an earlier study of the Oldman River (Fernet and Matkowski 1986), and therefore is not discussed in detail. All of the study reach observations fell within the ranges of the suitability curves generated for the source stream (Figure 7). The small differences in preference for the two study sites is indicative of limited availability in the study reach. A cover preference curve was not created in the earlier study, as cover was a limiting characteristic in the Oldman River. The cover preference curve developed from the Crowsnest River for juvenile rainbow trout is therefore available as a source stream suitability curve for this parameter.

Rainbow Trout Adults

The depth, velocity and substrate preference curves created for adult rainbow trout in Reach 3 of the Crowsnest River provide good agreement with those created for the source stream (Figure 8). The slight differences in preference for depth were due to the limited availability in the study reach, as indicated by the relatively good agreement of the predicted utilization curves with the observed utilization curves (Figure 9).

Examination of the cover suitability curves suggest that cover Types 5 and 55 were unavailable when the source stream data were obtained (Figure 8). The predicted utilization curve also suggested a lack of availability (Figure 10). A comparison of availabilities, however, indicated that this was not the case (Figure 11). As was concluded with rainbow trout fry, the habitat preference curve from the source stream should likely be modified to include a slight preference for cover Types 5 and 55, to increase the transferability of these criteria between watercourses.

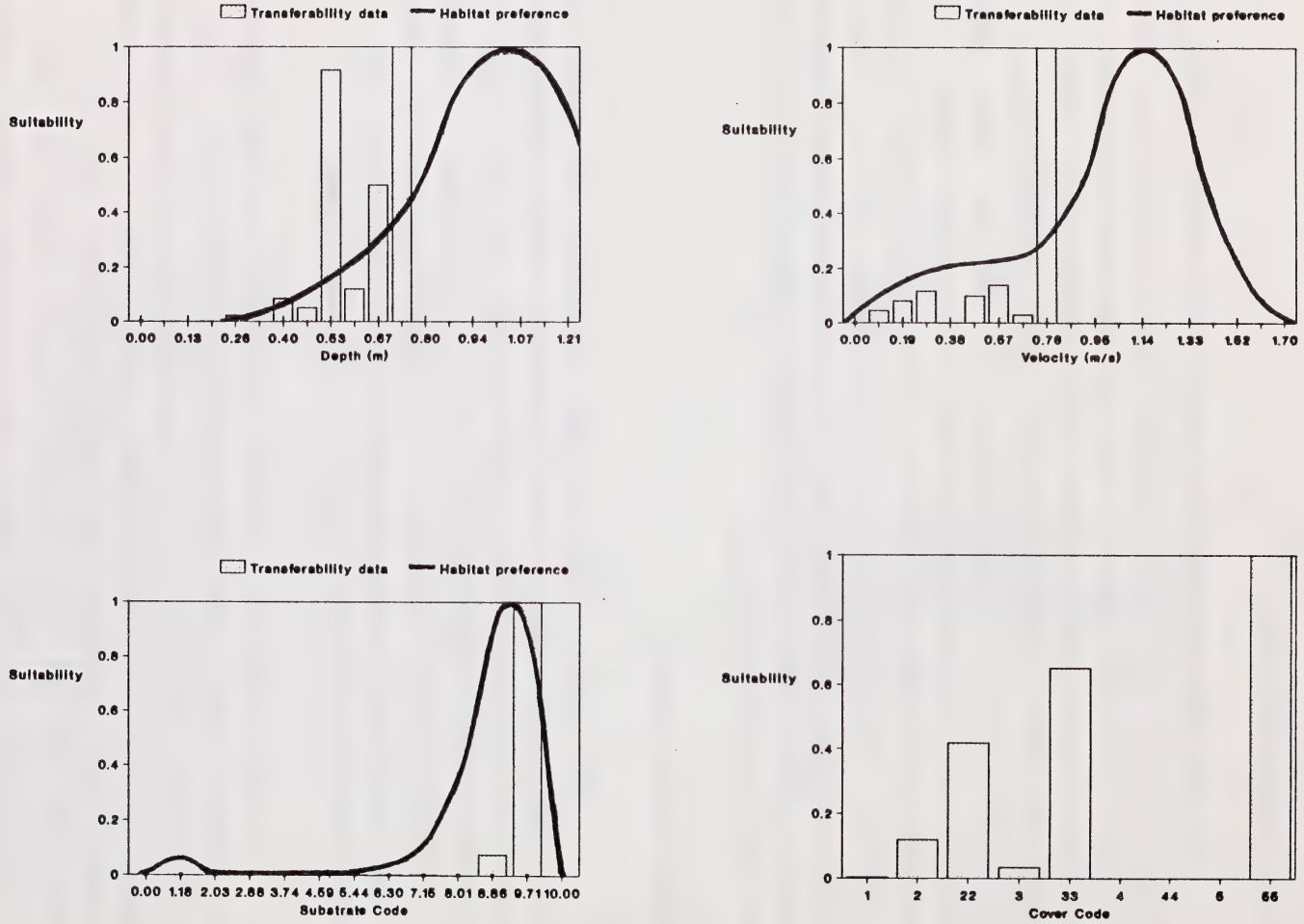



Figure 7. Preference and transferability data, rainbow trout juveniles.

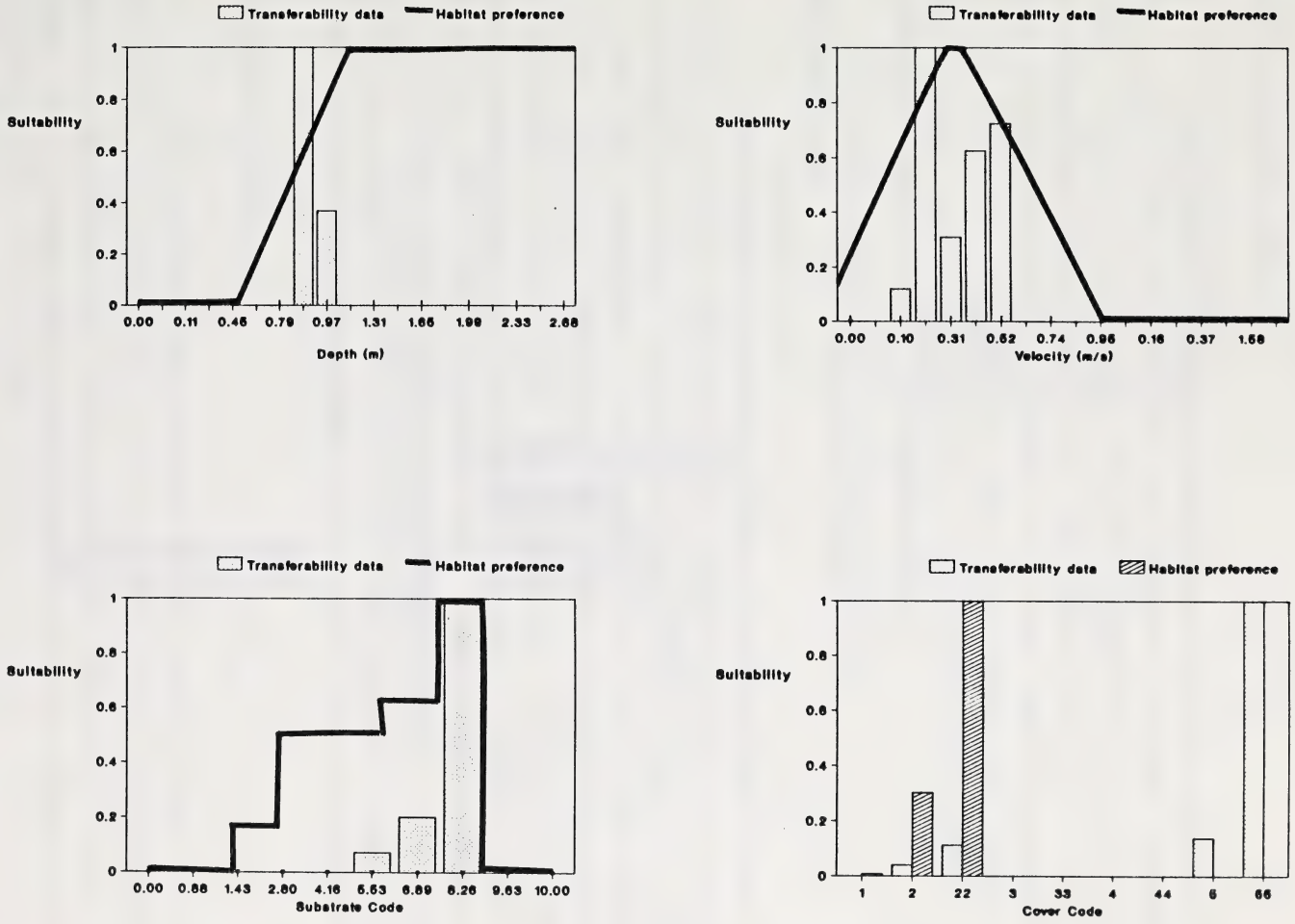



Figure 8. Preference and transferability data, rainbow trout adults.

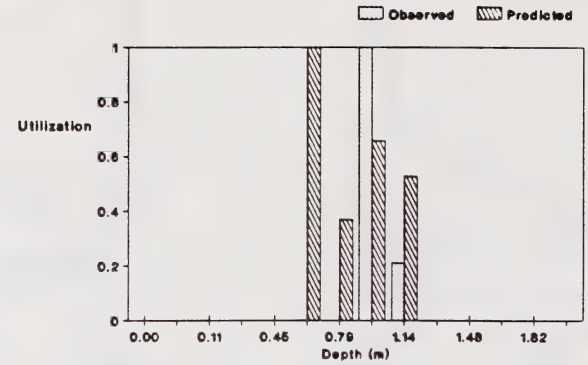



Figure 9. Predicted and observed depth utilization, rainbow trout adults, Crowsnest River Reach 3.

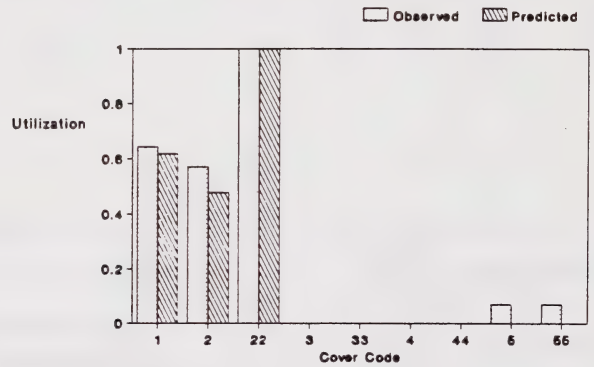



Figure 10. Predicted and observed cover utilization, rainbow trout adults, Crowsnest River Reach 3.

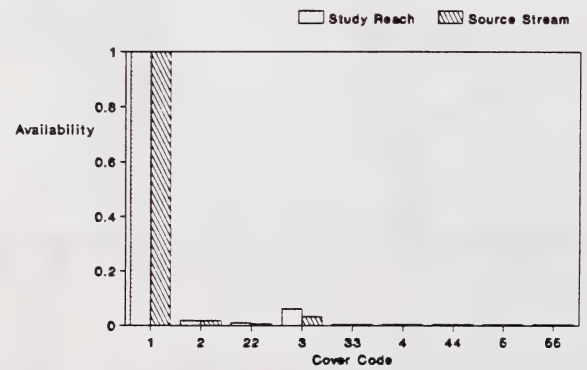



Figure 11. Comparison of cover distributions, rainbow trout adults, Crowsnest River

Spawning Rainbow Trout

The number of rainbow trout spawning observations in the study reach were insufficient to produce reliable preference curves. A test of transferability was conducted by superimposing the utilization observations of the study reach on the source stream suitability curves (Figure 12). The habitat measurements for each parameter obtained in the study reach fell within the source stream suitability curves. These data therefore suggest the source stream curves are transferable.

Brown Trout Fry

The habitat characteristics at points where brown trout fry were observed in the study reach were all within the ranges of the suitability curves created from the source stream data (Figure 13), with one exception. One brown trout fry in the Crowsnest River was found at a depth greater than the maximum identified in the preference criteria from the Bow River. As availability of depths greater than 0.3 m is not an issue in either study area (Figure 14), this result suggests that a very minor change could be made to the source stream suitability curve. In general, however, the brown trout fry data from the Crowsnest River indicate the Bow River habitat preference criteria for fry are transferable.

Brown Trout Juveniles

All habitat characteristics at points where juvenile brown trout were observed in the Crowsnest River were within the range of the suitability curves generated from the source stream (Figure 15). These results indicate the source stream data were transferable.

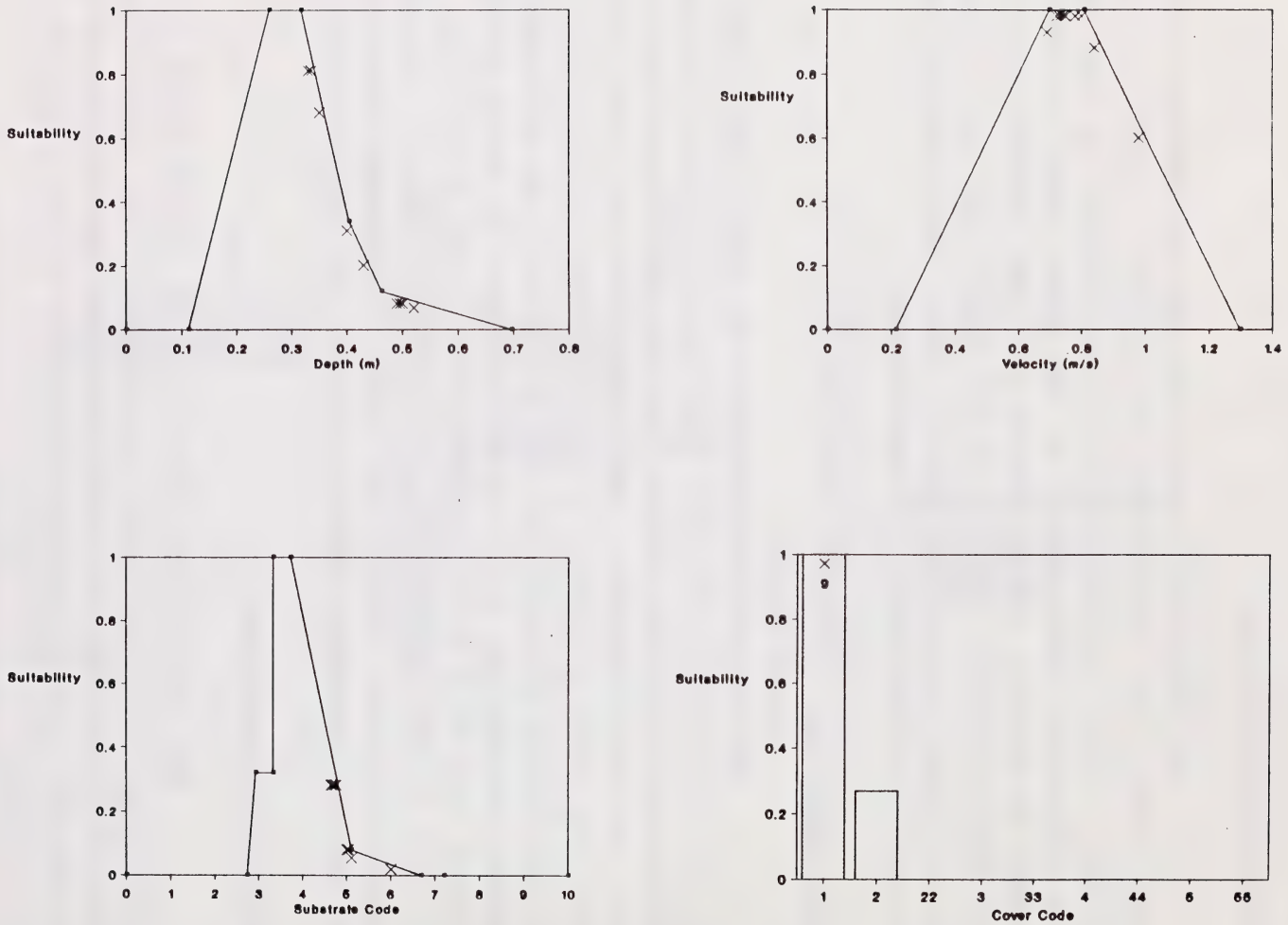
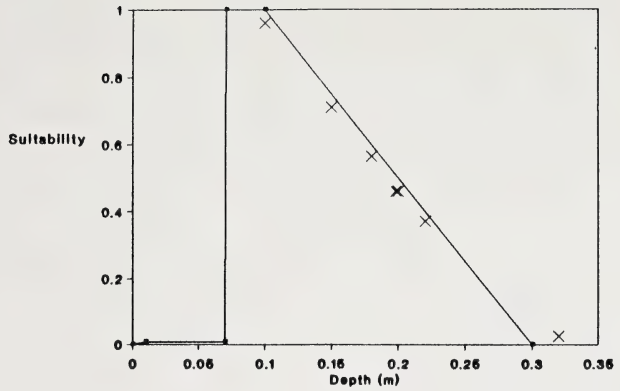
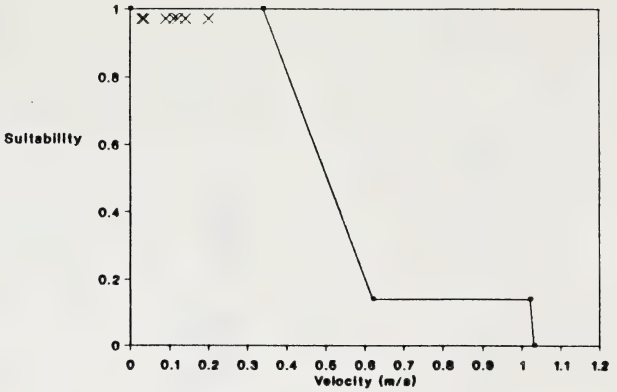
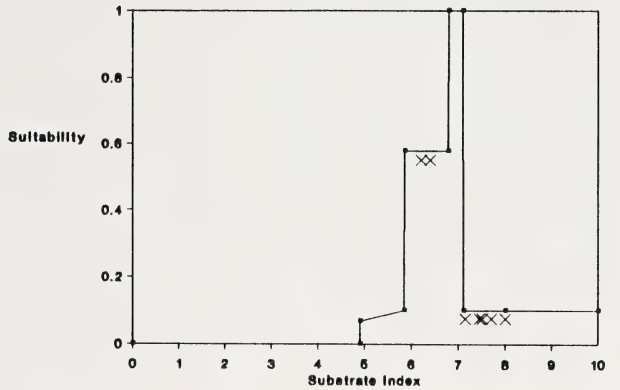



Figure 12. Preference and transferability data (x), rainbow trout spawning.



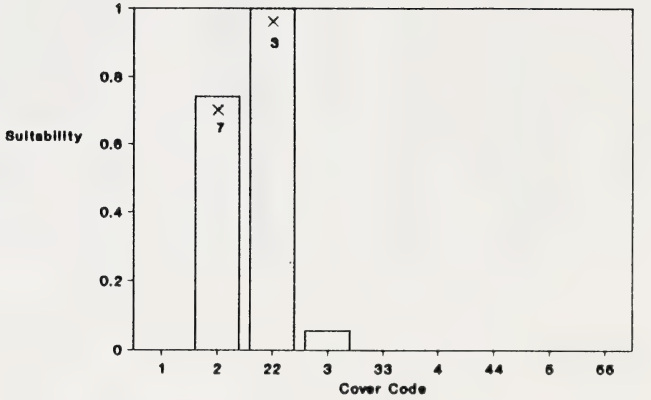




Figure 13. Preference and transferability data (x), brown trout fry.

# APPENDIX I

## RAINBOW TROUT UTILIZATION, AVAILABILITY AND PREFERENCE CRITERIA

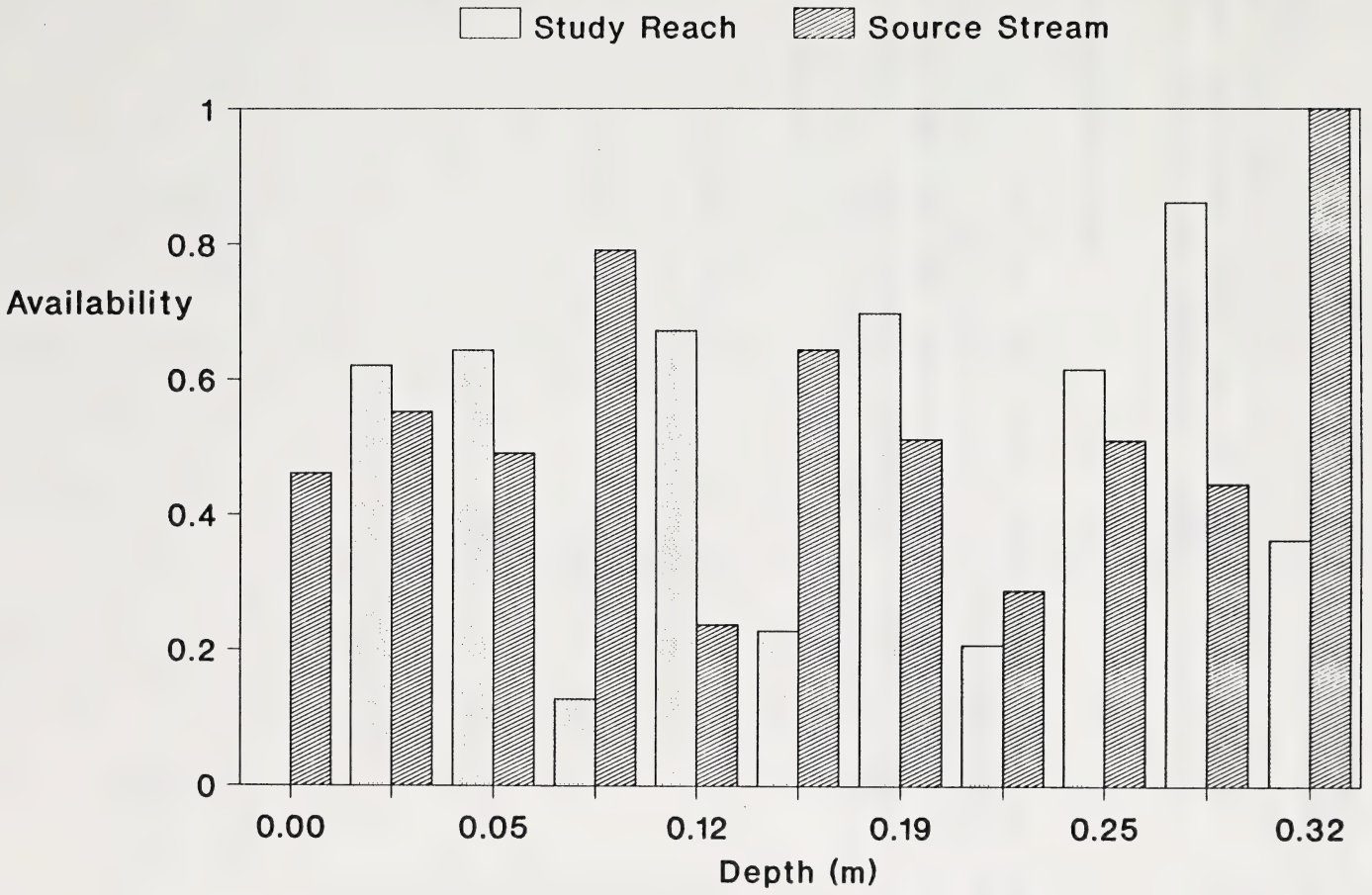
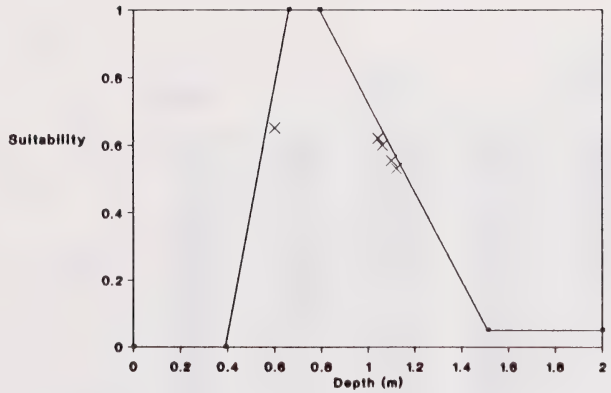
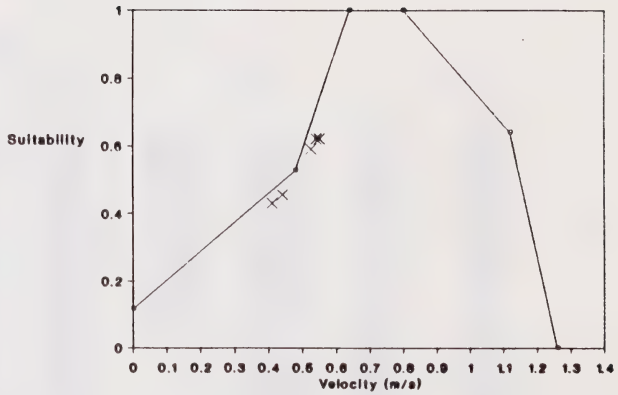
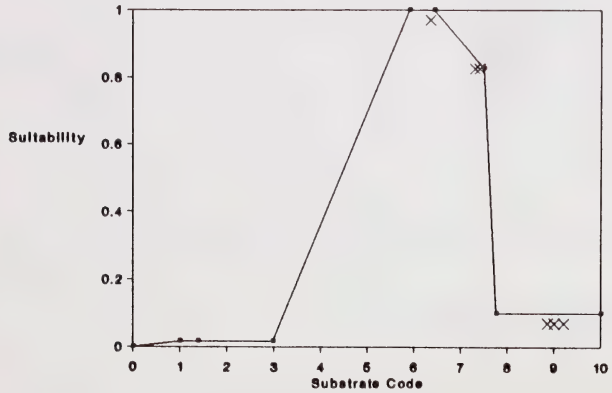



Figure 14. Comparison of depth distributions, brown trout fry, Crowsnest and Bow rivers.



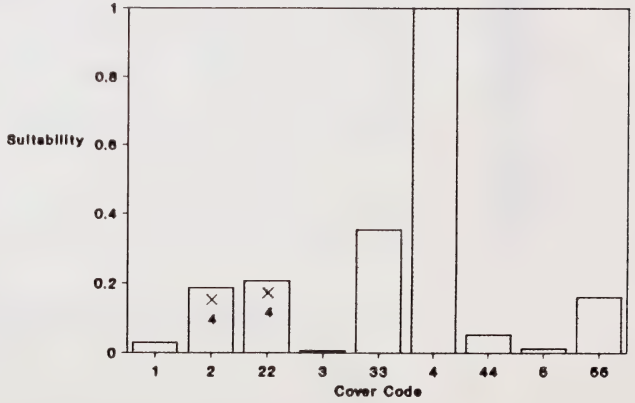



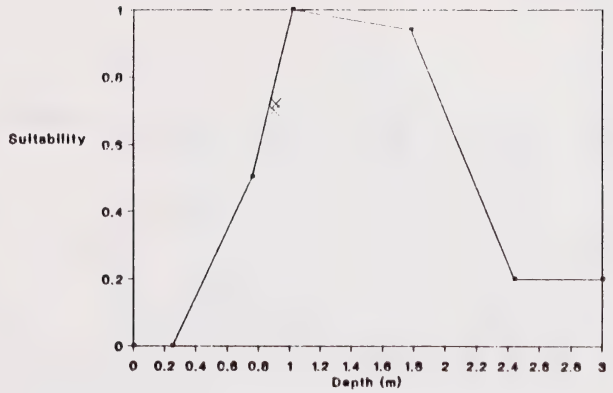

Figure 15. Preference and transferability data (x), brown trout juveniles.

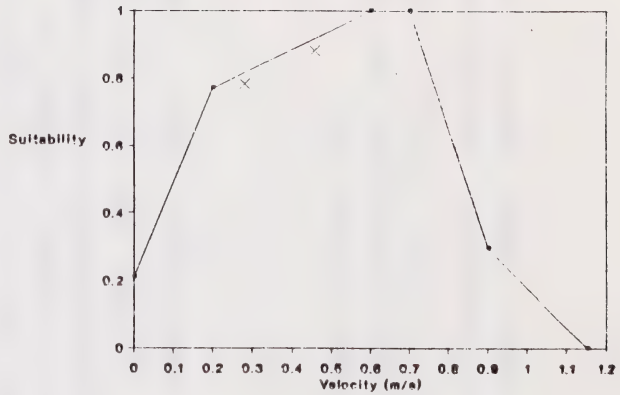
Brown Trout Adults

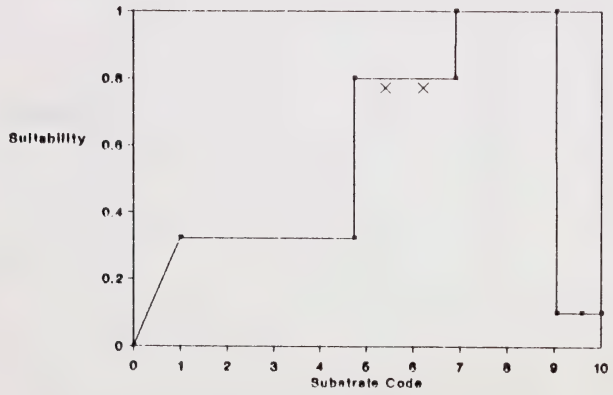
Only two brown trout adults were observed in the Crowsnest River study reaches, which provides an insufficient data base for any test of transferability. However, both fish preferred depths, velocities, substrates and cover types which were included in the source stream suitability curves (Figure 16).

Spawning Brown Trout

As was the case with brown trout adults, very few spawning brown trout observations (3) were obtained in the study reaches. All habitat characteristics measured at the redds fell within the source stream suitability curves (Figure 17), which suggests that the source stream suitability curves may be transferable.



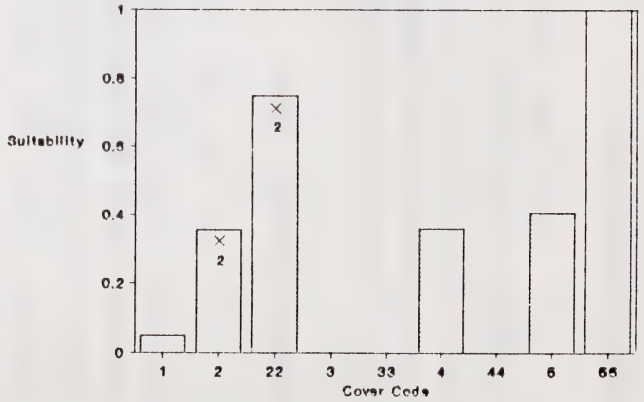




Figure 16. Preference and transferability data (x), brown trout adults.

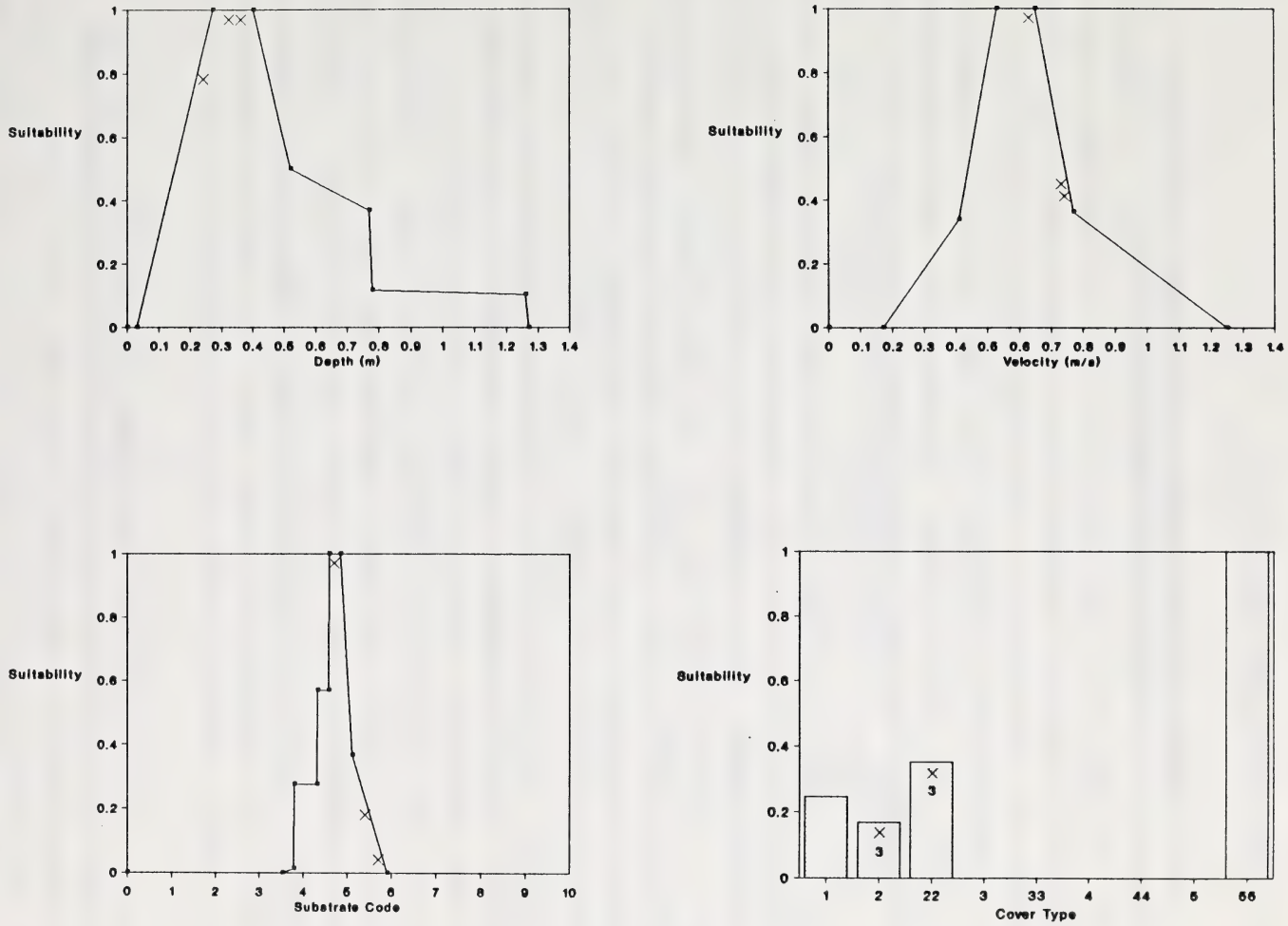



Figure 17. Preference and transferability data (x), brown trout spawning.

## 4.0 DISCUSSION AND CONCLUSION

Very low discharge rates were experienced in the Crowsnest River during the study reported here. A comparison of the discharge rates experienced in 1988 with the most complete set of historic records available from a Water Survey of Canada gauging station in the vicinity of the study reaches is presented in Table 5. Instantaneous discharge rates were typically one half of the historic mean monthly flows. The low flow conditions undoubtedly affected the fish populations in the Crowsnest River in 1988.

The immediate consequence of low water levels in a small river like the Crowsnest is a reduction in available habitats for the fish fauna. The frequency with which some life stage events occur, such as spawning, may be significantly reduced due to inappropriate habitat conditions during critical periods. The reduced availability of nursery and summer feeding habitats may cause fish to vacate regions of the river to find more suitable habitats, and/or use habitats which are marginal in suitability. All of these consequences likely occurred in the Crowsnest River in the open-water season of 1988. This was particularly evident in the case of juvenile and adult rainbow trout. Juveniles were observed to have very small territories, such that high numbers were present in any available rearing habitat. Adults were observed to exhibit a schooling type of behaviour in pools where depths were suitable for use by this life stage, as opposed to the territorial behaviour which would be anticipated in feeding areas.

Due to the small numbers of individuals in the study reaches of all life stages of brown trout and rainbow trout (with the exception of rainbow trout juveniles), the results of analyzing the transferability of the brown trout and rainbow trout habitat preference criteria developed by Fernet et al. (1989) were generally inconclusive. With the following exceptions, however,

**TABLE 5**

**COMPARISON OF HISTORIC CROWSNEST RIVER DISCHARGE RATES WITH THOSE EXPERIENCED IN 1988**

| DATE, 1988 | INSTANTANEOUS DISCHARGE ($m^3/s$) REACH 2 | REACH 3 | HISTORIC MEAN MONTHLY[1] FLOW ($m^3/s$) | |
|---|---|---|---|---|
| 26-27 April | 3.85 | 4.15 | April | 8.14 |
| 26-27 May | 9.51 | 9.87 | May | 19.50 |
| 5-12 July | 4.36 | | July | 10.50 |
| 8-11 August | 2.70 | | August | 5.54 |
| 11-12 August | | 2.55 | | |
| 10 October | 2.32 | | October | 4.60 |

[1] Crowsnest River near Lundbreck, WSC Station No. 05AA002, period of record 1908 to 1931.

the limited results did tend to support the transferability of criteria between watercourses. The following information is likely indicative of the target species using marginal components of the habitats which were available in the Crowsnest River in the summer of 1988:

- Rainbow trout fry above Lundbreck Falls made some use of habitats with slightly greater depths and velocities than those downstream of the falls. Upstream fry also exhibited a preference for cover Types 5 and 55 (combination instream object and overhead and its edge effect), which was not noted in the downstream area where the habitat preference curves were developed. These results suggest that the source stream curves for rainbow trout fry depth, velocity and cover preference may be too restrictive.

- Rainbow trout adults in the upper Crowsnest River study reach were also found to have a preference for cover Types 5 and 55. These results suggest that a minor change could be made to the source stream suitability curve to include this preference for cover Types 5 and 55.

## 5.0 REFERENCES CITED

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the Instream Flow Incremental Methodology. Instream Flow Information Paper No. 21. U.S. Fish and Wildlife Service, Biol. Rep. 86 (7). 235 pp.

Fernet, D.A. and S.M. Matkowski. 1986. Oldman River Dam environmental mitigation/opportunities plan instream flow study. Fish distribution, abundance, critical habitats and relationships with streamflow downstream of the Oldman River damsite. Prepared for Alberta Environment, Planning Division. 137 pp + App.

Fernet, D.A. and G.L. Walder. 1986. The development of habitat suitability criteria for use with the Instream Flow Incremental Methodology. A manual for the Province of Alberta. Prepared for Alberta Fish and Wildlife Division, Habitat Branch, Edmonton.

Fernet, D.A., R.F. Courtney, N.E. Barnes and C.P. Bjornson. 1989. Instream flow requirements for fishes downstream of the Oldman River Dam. Prepared for Alberta Public Works, Supply and Services, Oldman River Dam Project, Edmonton (Draft Report).

Kinzie, R.A. and J.I. Ford. 1988. A test of transferability of habitat utilization curves. In: Proceedings of a workshop on the development and evaluation of habitat suitability criteria. Bovee, K., and J.R. Zuboy, eds. U.S. Fish and Wildlife Service, Biol. Rep. 88 (11). 407 pp.

Trihey, E.W. and D.L. Wegner. 1981. Field data collection procedures for use with the Physical Habitat Simulation System of the Instream Flow Group. Partial revision in February, 1983. Draft report. Cooperative Instream Flow Service Group, Fort Collins, Colorado. 131 pp.

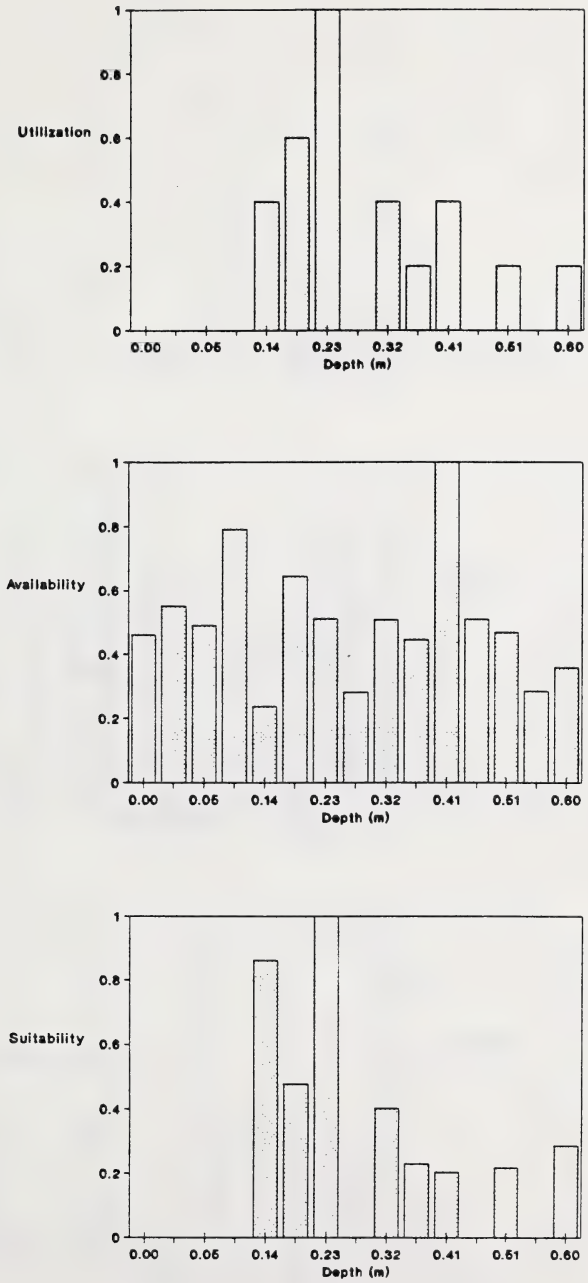



Figure I-1. Depth utilization, availability and preference criteria, Crowsnest River, rainbow trout fry (n=17).

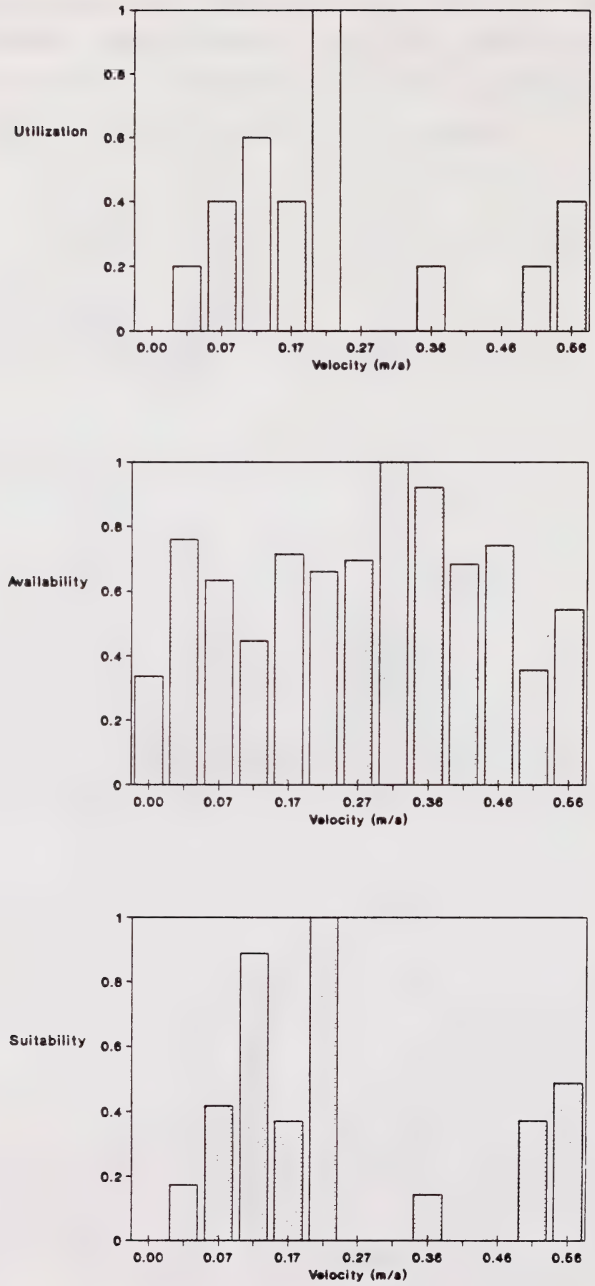



Figure I-2. Velocity utilization, availability and preference criteria, rainbow trout fry (n=17).

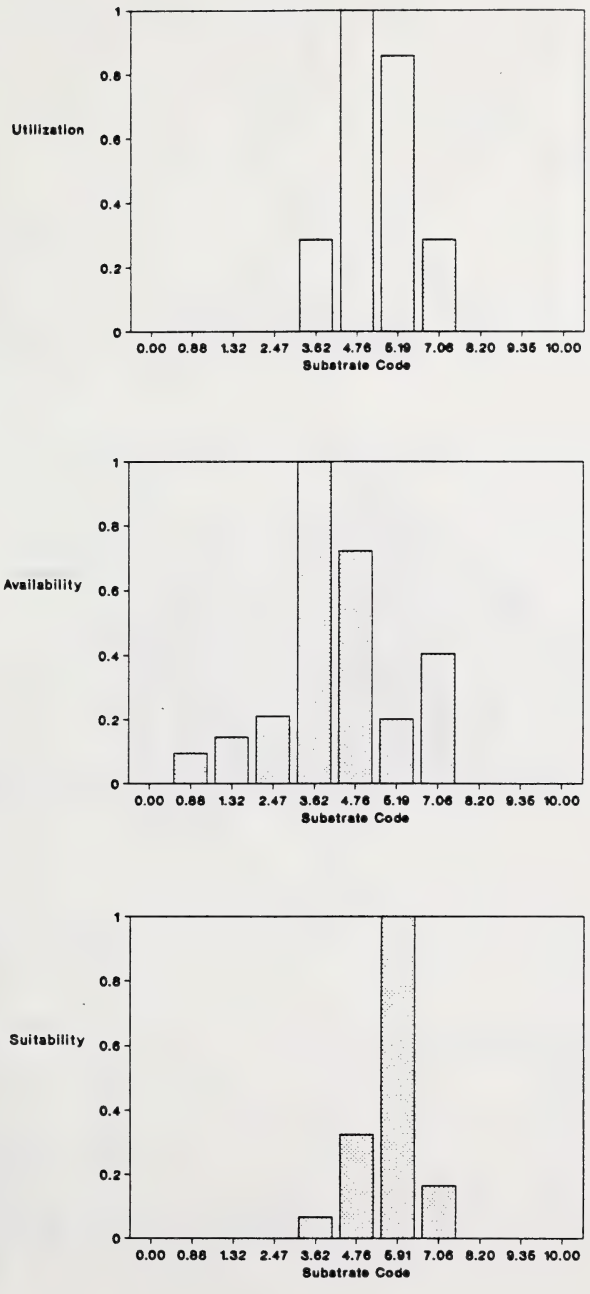



Figure I-3. Substrate utilization, availability and preference criteria, rainbow trout fry (n=17).

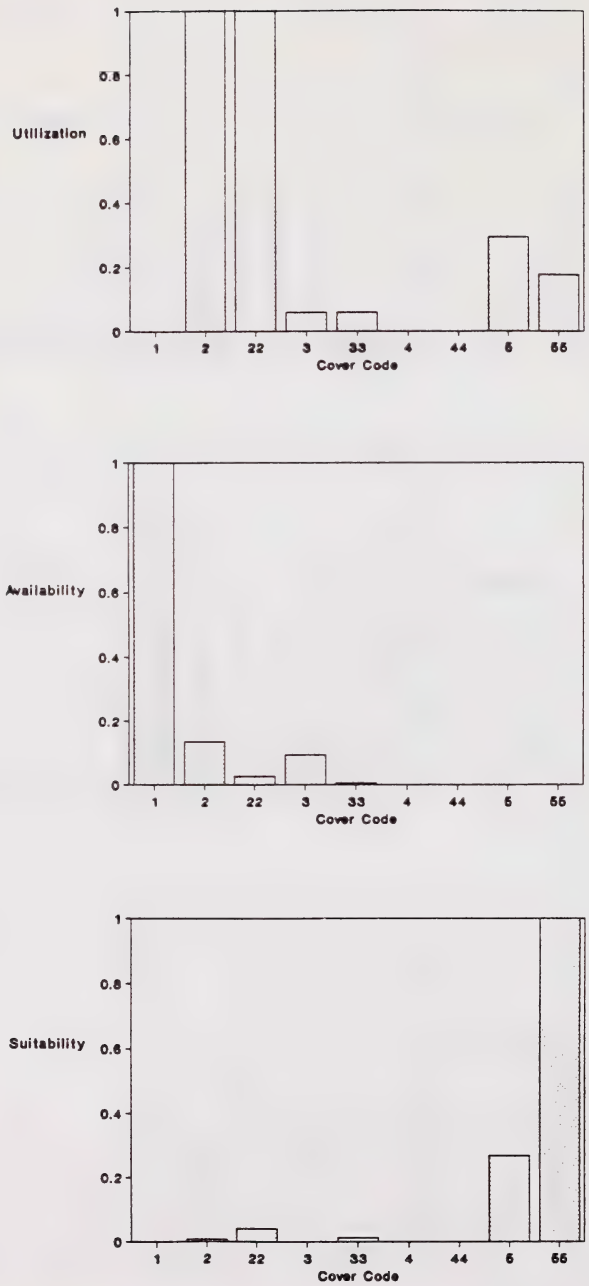



Figure I-4. Cover utilization, availability and preference criteria, Crowsnest River, rainbow trout fry (n=17).

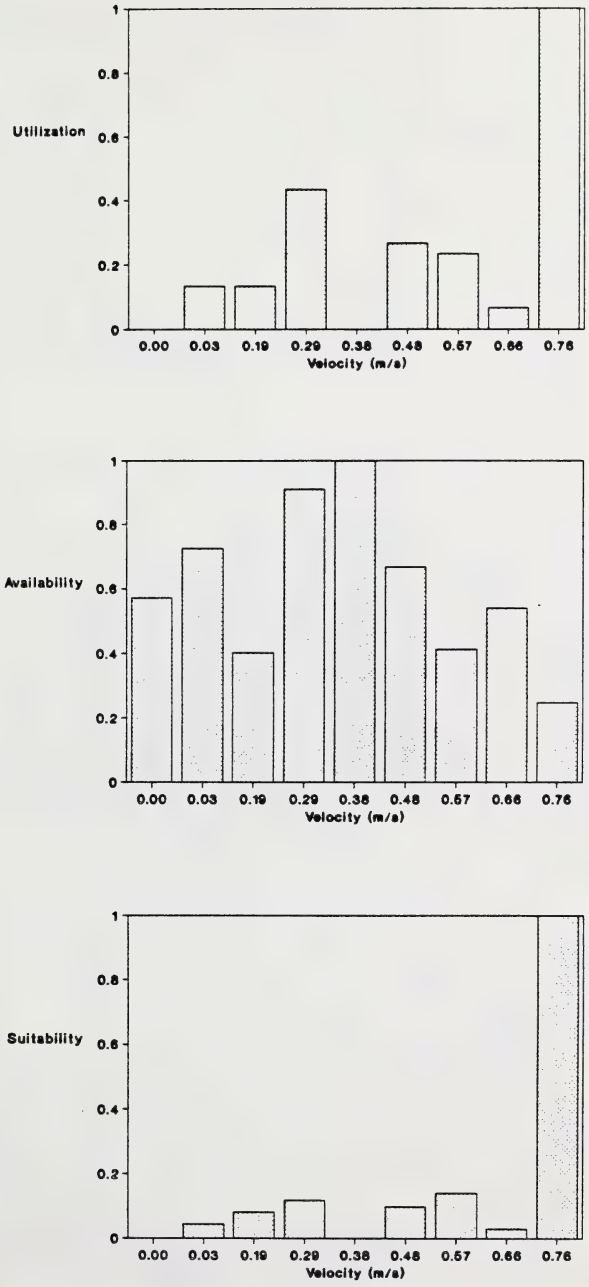



Figure I-6. Velocity utilization, availability and preference criteria, rainbow trout juveniles (n=68).

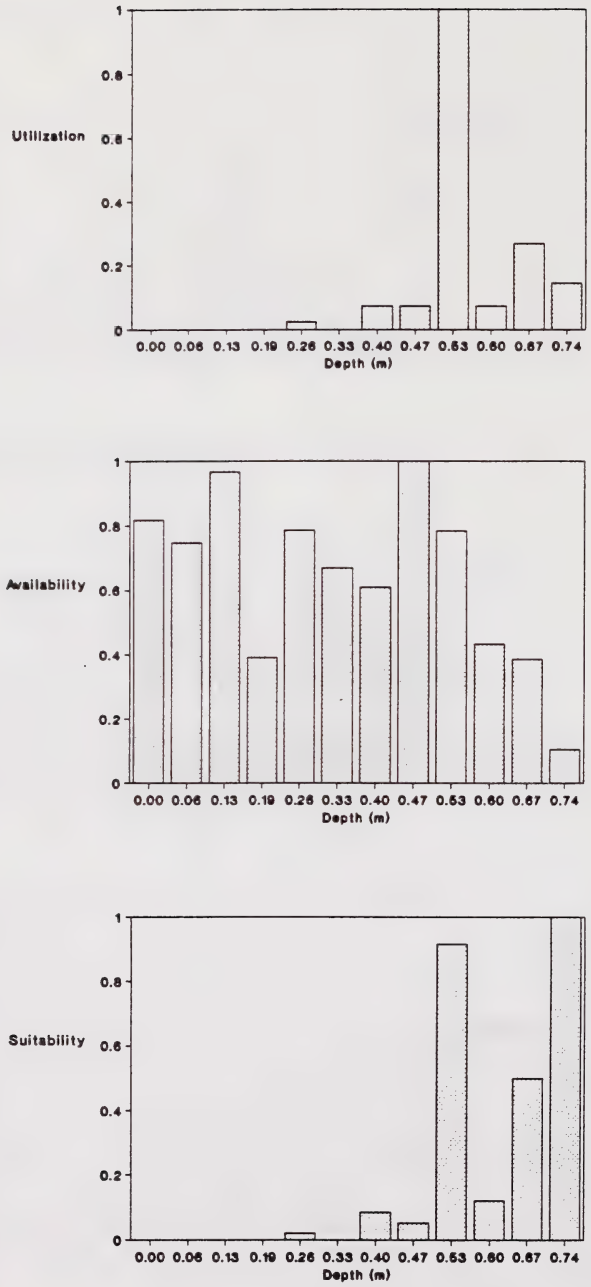



Figure I-5. Depth utilization, availability and preference criteria, Crowsnest River, rainbow trout juveniles (n=68).

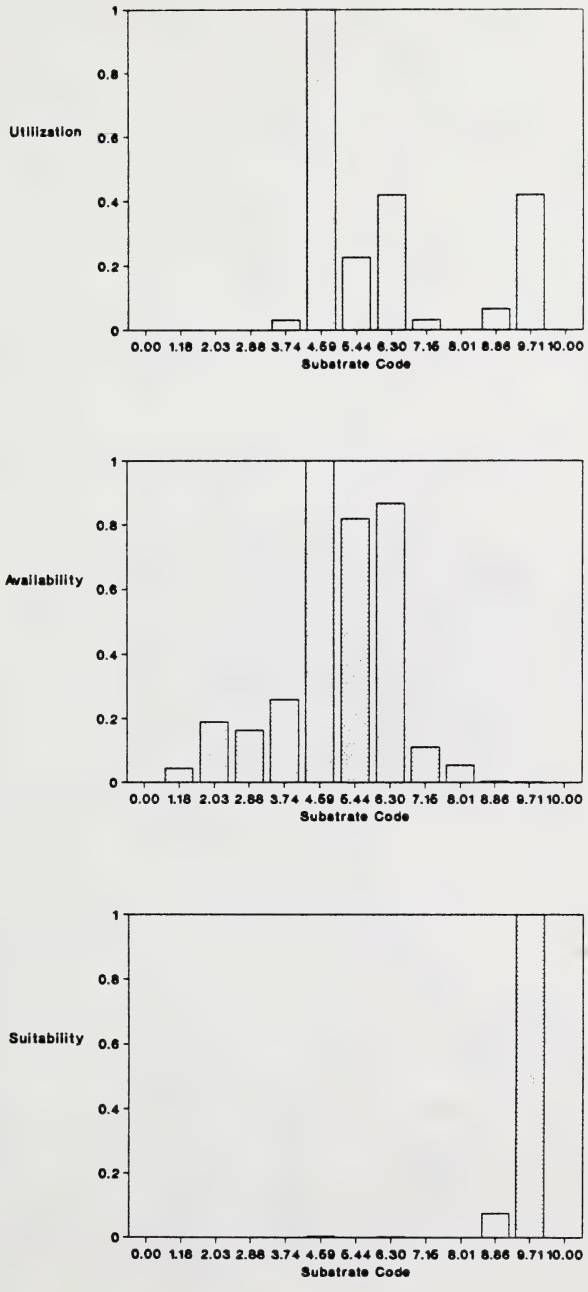



Figure I-7. Substrate utilization, availability and preference criteria, rainbow trout juveniles (n=68).

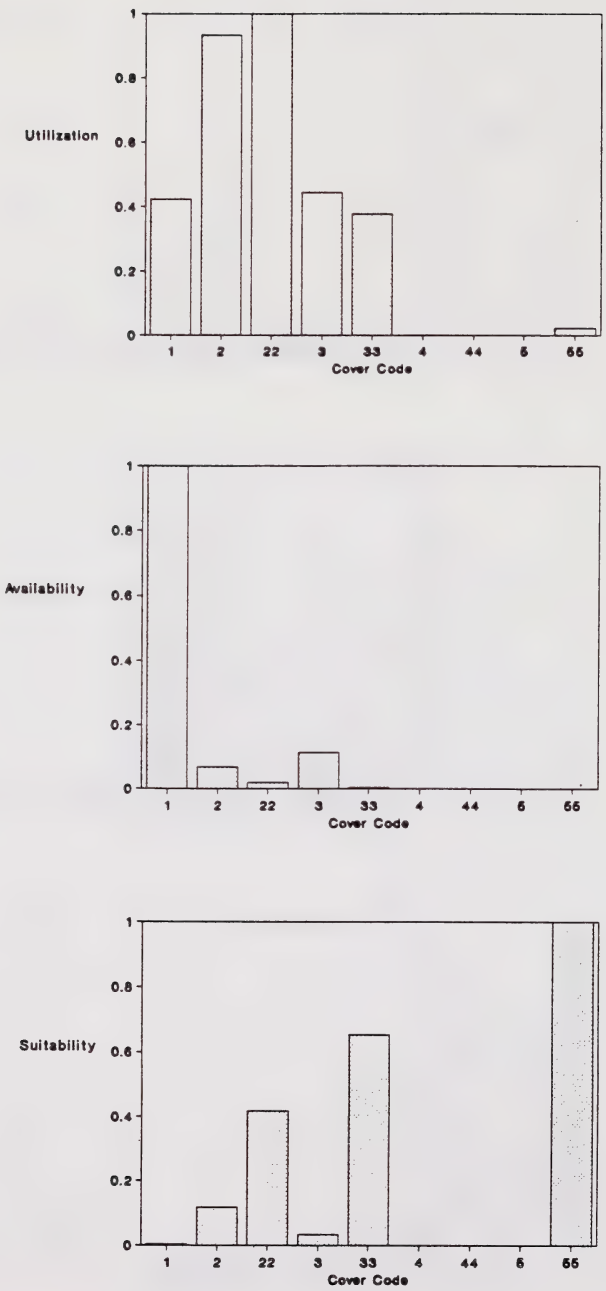



Figure I-8. Cover utilization, availability and preference criteria, Crowsnest River, rainbow trout juveniles (n=68).

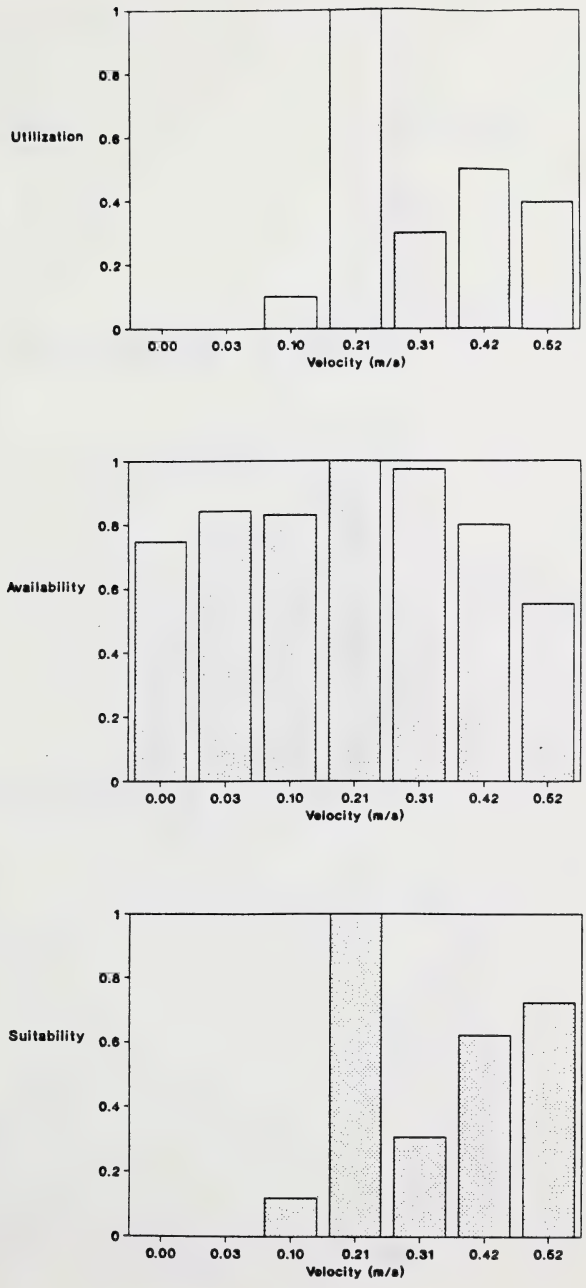



Figure I-10. Velocity utilization, availability and preference criteria, rainbow trout adults (n=23).

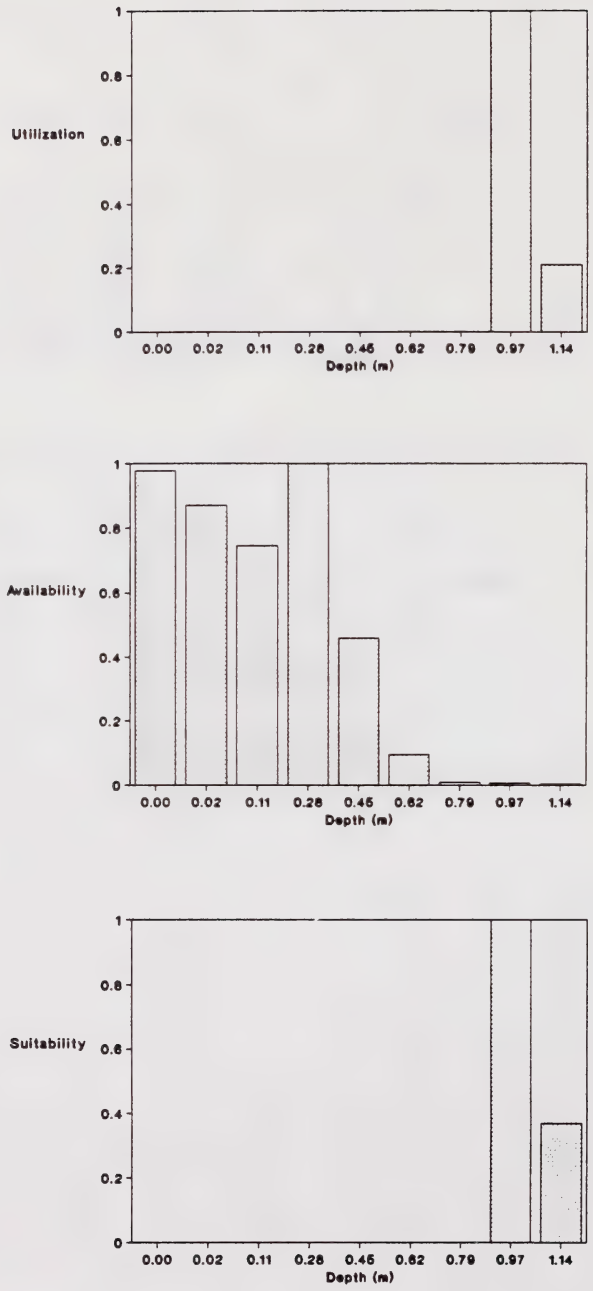



Figure I-9. Depth utilization, availability and preference criteria, Crowsnest River, rainbow trout adults (n=23).

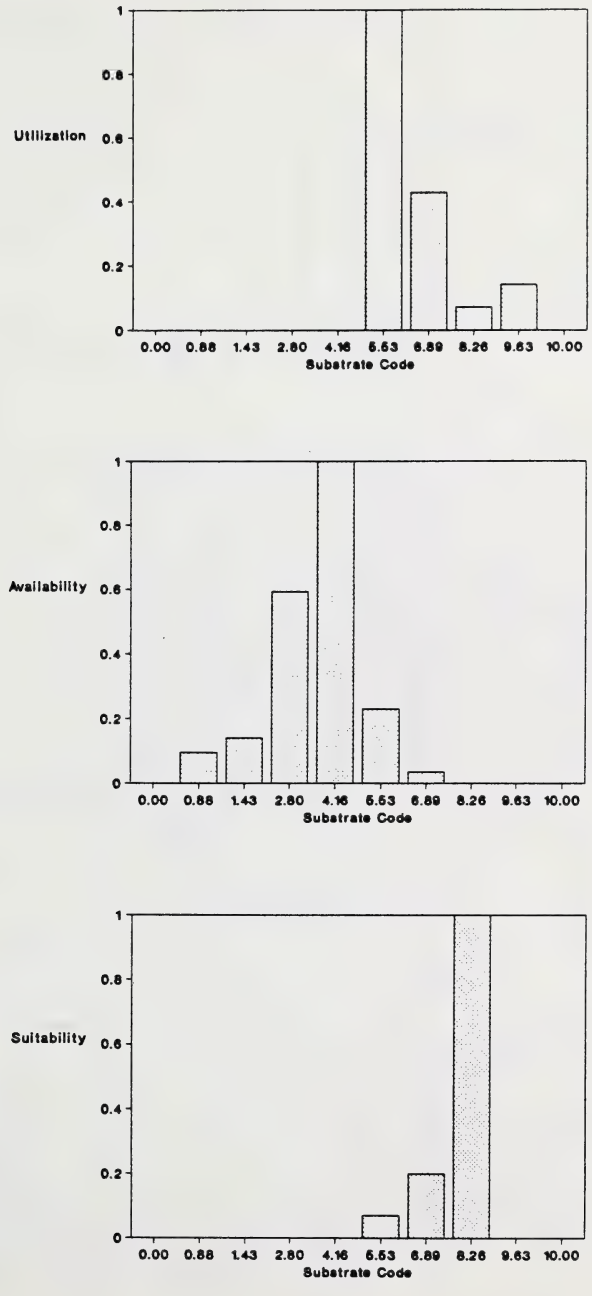



Figure I-11. Substrate utilization, availability and preference criteria, rainbow trout adults (n=23).

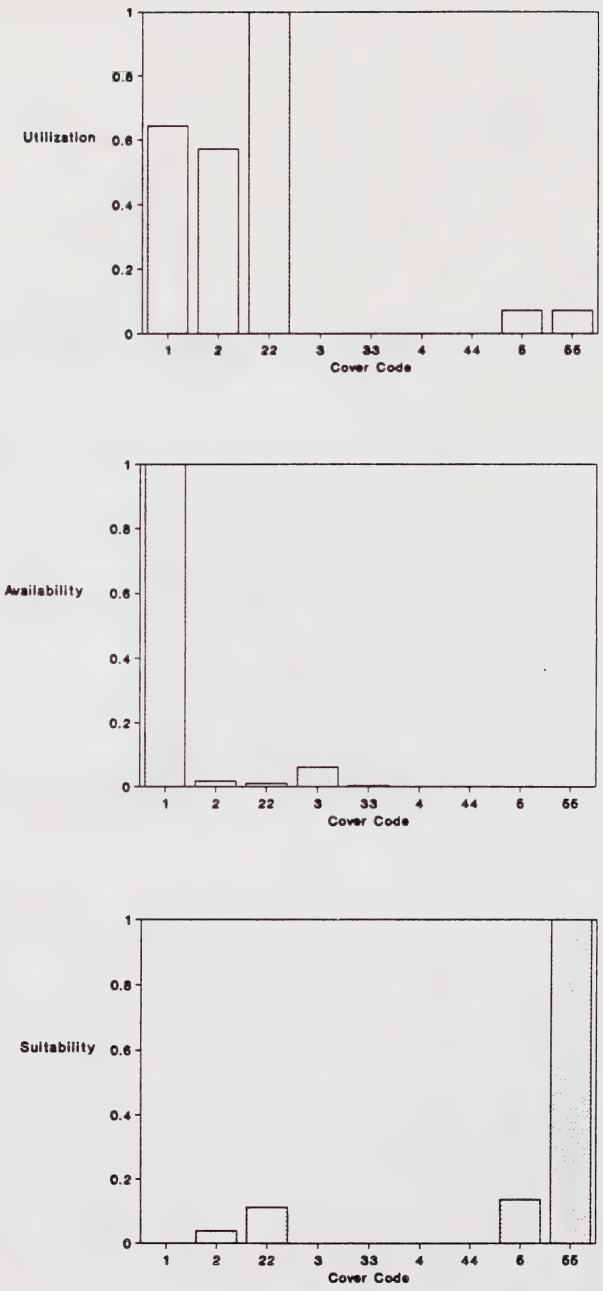



Figure I-12. Cover utilization, availability and preference criteria, Crowsnest River, rainbow trout adults (n=23).

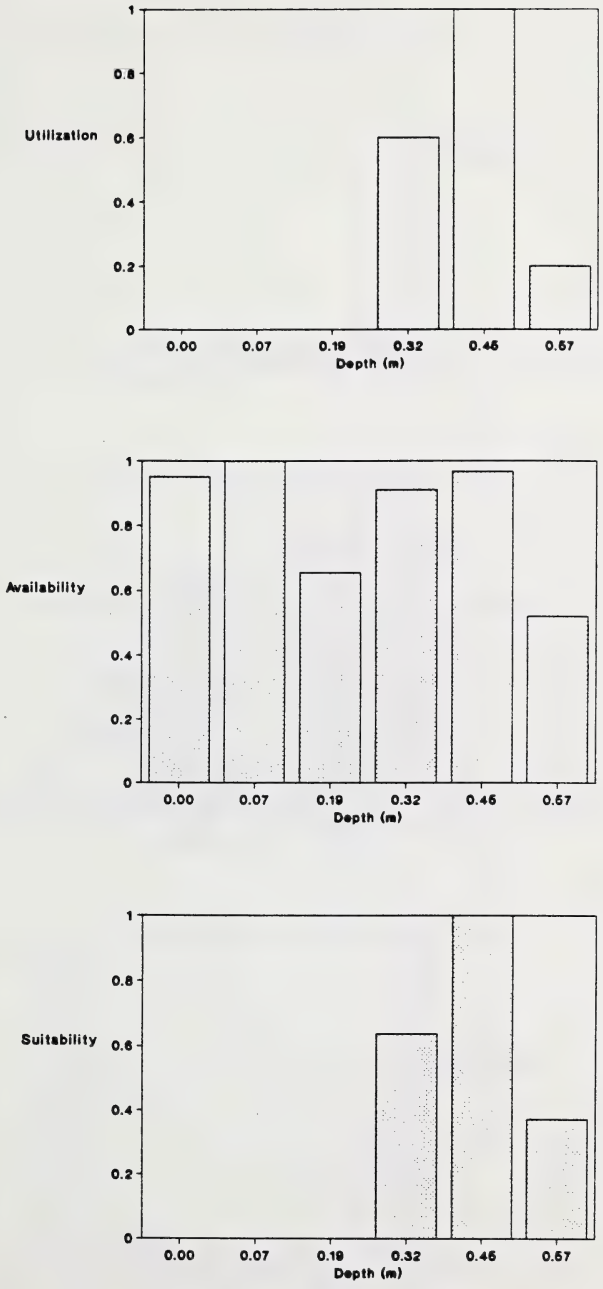



Figure I-13. Depth utilization, availability and preference criteria, Crowsnest River, rainbow trout spawning (n=9).

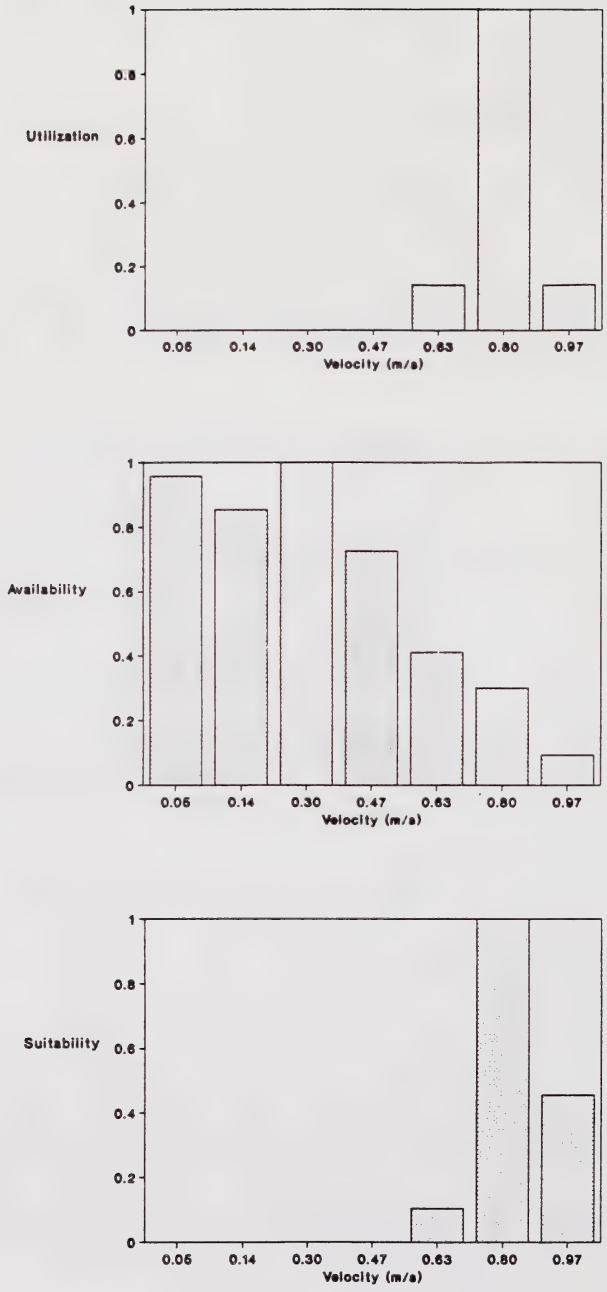



Figure I-14. Velocity utilization, availability and preference criteria, rainbow trout spawning (n=9).

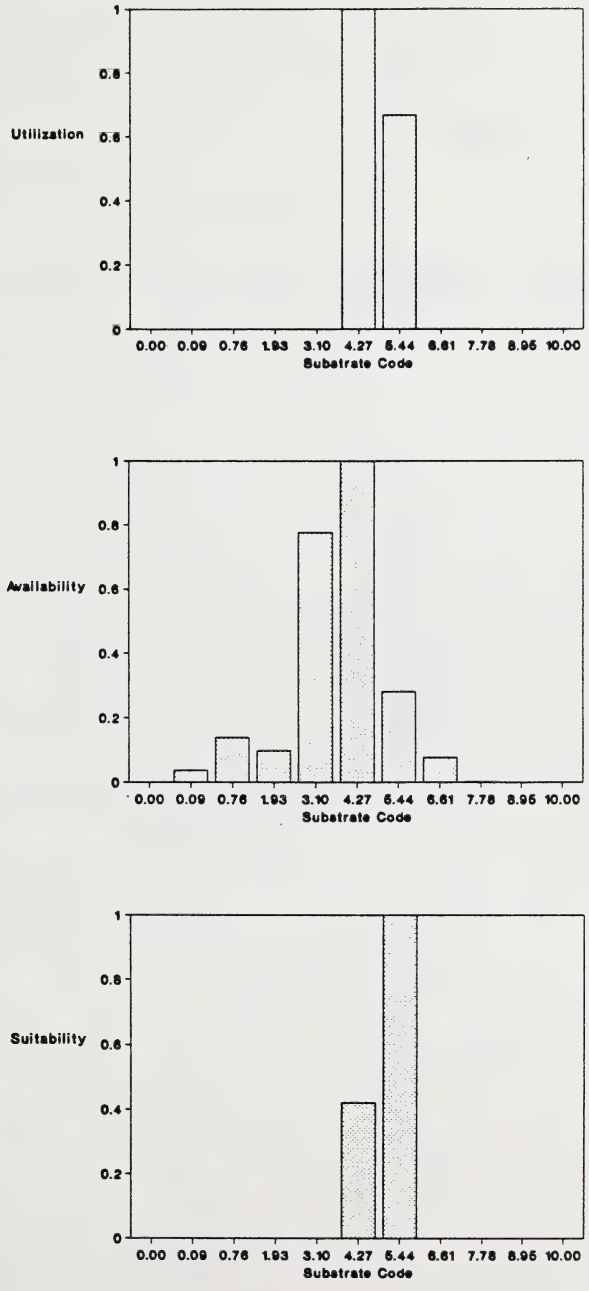



Figure I-15. Substrate utilization, availability and preference criteria, rainbow trout spawning (n=9).

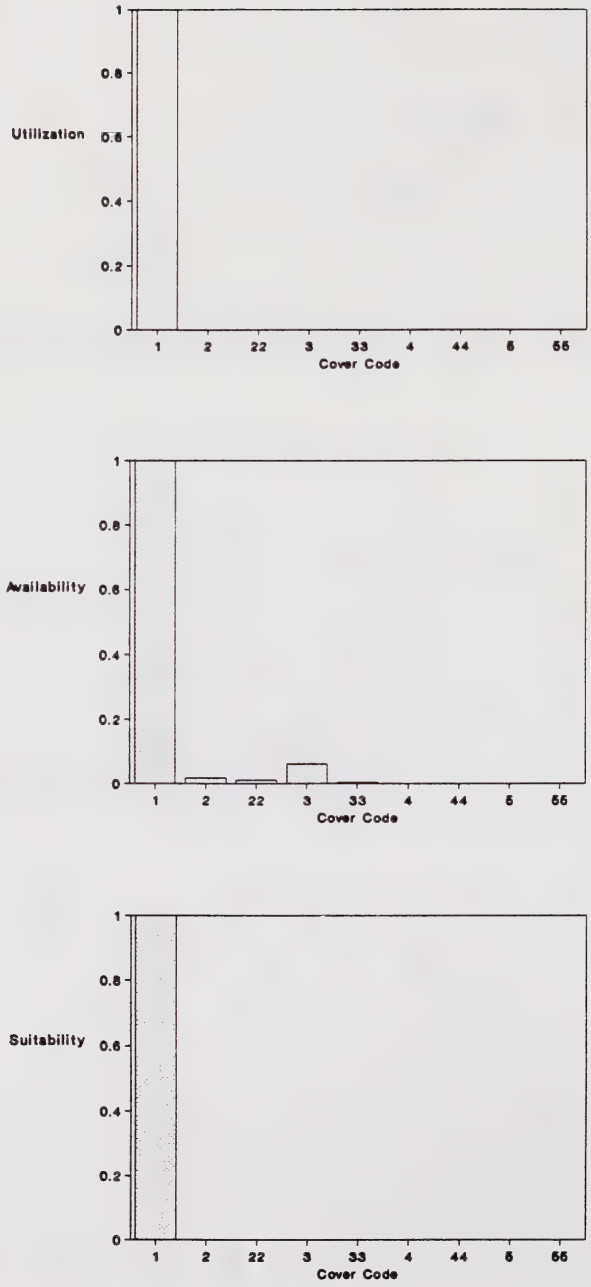



Figure I-16. Cover utilization, availability and preference criteria, Crowsnest River, rainbow trout spawning (n=9).

# APPENDIX II

## EVALUATION OF SAMPLE SIZE REQUIREMENTS FOR THE DEVELOPMENT OF HABITAT PREFERENCE CRITERIA

TABLE II - 1

HABITAT PREFERENCE SAMPLE SIZE REQUIREMENTS, BROWN TROUT

| Variable | Mean | Variance | Students t | Accuracy | Observed n | Calculated n |
|---|---|---|---|---|---|---|
| **Brown trout spawning** | | | | | | |
| Substrate | 5.690 | 0.240 | 1.975 | 0.50 | 162 | 4 |
| Depth | 0.452 | 0.505 | 1.975 | 0.10 | 162 | 197 |
| Velocity | 0.560 | 0.560 | 1.975 | 0.10 | 162 | 219 |
| **Brown trout adults** | | | | | | |
| Substrate | 5.611 | 4.860 | 2.007 | 0.50 | 53 | 79 |
| Depth | 1.328 | 0.165 | 2.007 | 0.10 | 53 | 67 |
| Velocity | 0.254 | 0.029 | 2.007 | 0.05 | 53 | 47 |
| **Brown trout Juveniles** | | | | | | |
| Substrate | 6.955 | 0.434 | 2.007 | 0.50 | 51 | 7 |
| Depth | 0.779 | 0.037 | 2.007 | 0.10 | 51 | 15 |
| Velocity | 0.662 | 0.068 | 2.007 | 0.10 | 51 | 28 |
| **Brown trout fry** | | | | | | |
| Substrate | 7.436 | 0.199 | 1.975 | 0.50 | 156 | 4 |
| Depth | 0.150 | 0.003 | 1.975 | 0.05 | 156 | 5 |
| Velocity | 0.227 | 0.027 | 1.975 | 0.05 | 156 | 43 |

TABLE II - 2

HABITAT PREFERENCE SAMPLE SIZE REQUIREMENTS, RAINBOW TROUT

| Variable | Mean | Variance | Students t | Accuracy | Observed n | Calculated n |
|---|---|---|---|---|---|---|
| **Rainbow trout spawning** | | | | | | |
| Substrate | 4.224 | 0.436 | 1.976 | 0.50 | 150 | 7 |
| Depth | 0.326 | 0.008 | 1.976 | 0.10 | 150 | 3 |
| Velocity | 0.730 | 0.023 | 1.976 | 0.10 | 152 | 9 |
| **Rainbow trout adults (Q = 4.36)** | | | | | | |
| Substrate | 7.399 | 2.859 | 1.982 | 0.50 | 112 | 45 |
| Depth | 0.982 | 0.047 | 1.982 | 0.10 | 114 | 19 |
| Velocity | 0.384 | 0.025 | 1.982 | 0.05 | 114 | 40 |
| **Rainbow trout adults (Q = 2.37)** | | | | | | |
| Substrate | 7.011 | 2.654 | 2.005 | 0.50 | 54 | 43 |
| Depth | 0.880 | 0.111 | 2.005 | 0.10 | 54 | 45 |
| Velocity | 0.283 | 0.028 | 2.005 | 0.05 | 54 | 45 |
| **Rainbwo trout fry** | | | | | | |
| Substrate | 7.519 | 0.490 | 1.975 | 0.50 | 155 | 8 |
| Depth | 0.179 | 0.004 | 1.975 | 0.05 | 156 | 6 |
| Velocity | 0.069 | 0.006 | 1.975 | 0.05 | 156 | 10 |

TABLE II - 3

HABITAT PREFERENCE SAMPLE SIZE REQUIREMENTS, WALLEYE ADULTS

| Variable | Mean | Variance | Students t | Accuracy | Observed n | Calculated n |
|---|---|---|---|---|---|---|
| **Walleye adults (day; Q = 12.3)** | | | | | | |
| Substrate | 5.514 | 5.460 | 2.002 | 0.50 | 58 | 88 |
| Depth | 1.797 | 0.201 | 2.002 | 0.10 | 58 | 81 |
| Velocity | 0.163 | 0.006 | 2.002 | 0.05 | 58 | 10 |
| **Walleye adults (day; Q = 13.4)** | | | | | | |
| Substrate | 5.703 | 7.882 | 2.042 | 0.50 | 30 | 132 |
| Depth | 1.688 | 0.224 | 2.042 | 0.10 | 30 | 94 |
| Velocity | 0.120 | 0.005 | 2.042 | 0.05 | 30 | 8 |
| **Walleye adults (day; Q = 15)** | | | | | | |
| Substrate | 4.064 | 35.929 | 2.145 | 0.50 | 14 | 662 |
| Depth | 1.877 | 3.388 | 2.145 | 0.10 | 14 | 1559 |
| Velocity | 0.161 | 0.030 | 2.145 | 0.05 | 14 | 55 |
| **Walleye adults (day; Q = 20)** | | | | | | |
| Substrate | 5.775 | 0.419 | 2.306 | 0.50 | 8 | 9 |
| Depth | 1.315 | 0.153 | 2.306 | | | |

TABLE II - 4

HABITAT PREFERENCE SAMPLE SIZE REQUIREMENTS, WALLEYE JUVENILES

| Variable | Mean | Variance | Students t | Accuracy | Observed n | Calculated n |
|---|---|---|---|---|---|---|
| **Walleye juveniles (day; Q = 12)** | | | | | | |
| Substrate | 4.849 | 6.862 | 1.999 | 0.50 | 62 | 110 |
| Depth | 1.553 | 0.148 | 1.999 | 0.10 | 62 | 60 |
| Velocity | 0.157 | 0.005 | 1.999 | 0.05 | 62 | 8 |
| **Walleye juveniles (day; Q = 13)** | | | | | | |
| Substrate | 5.187 | 4.035 | 2.101 | 0.50 | 18 | 72 |
| Depth | 1.585 | 0.320 | 2.101 | 0.10 | 18 | 142 |
| Velocity | 0.151 | 0.004 | 2.101 | 0.05 | 18 | 7 |
| **Walleye juveniles (day; Q = 22)** | | | | | | |
| Substrate | 4.586 | 2.267 | 2.03 | 0.50 | 19 | 40 |
| Depth | 1.288 | 0.242 | 2.093 | 0.10 | 19 | 106 |
| Velocity | 0.267 | 0.018 | 2.093 | 0.05 | 19 | 32 |
| **Walleye juveniles (night; Q = 20)** | | | | | | |
| Substrate | 5.610 | 5.247 | 2.228 | 0.50 | 10 | 105 |
| Depth | 1.347 | 0.254 | 2.228 | 0.10 | 10 | 127 |
| Velocity | 0.194 | 0.013 | 2.228 | 0.05 | 10 | 27 |
| **Walley juveniles (night; Q = 13)** | | | | | | |
| Substrate | 4.941 | 3.470 | 2.018 | 0.50 | 42 | 57 |
| Depth | 1.049 | 0.155 | 2.018 | 0.10 | 42 | 63 |
| Velocity | 0.166 | 0.007 | 2.018 | 0.05 | 42 | 12 |

TABLE II - 5

HABITAT PREFERENCE SAMPEL SIZE REQUIREMENTS, SAUGER

| Variable | Mean | Variance | Students t | Accuracy | Observed n | Calculated n |
|---|---|---|---|---|---|---|
| **Sauger adults (day; Q = 12.3)** | | | | | | |
| Substrate | 5.892 | 10.291 | 2.002 | 0.50 | 57 | 165 |
| Depth | 1.715 | 0.118 | 2.002 | 0.10 | 57 | 48 |
| Velocity | 0.098 | 0.001 | 2.001 | 0.05 | 57 | 2 |
| **Sauger adults (day; Q = 21.2)** | | | | | | |
| Substrate | 5.833 | 8.866 | 2.776 | 0.50 | 4 | 274 |
| Depth | 1.365 | 0.092 | 2.776 | 0.10 | 4 | 72 |
| Velocity | 0.214 | 0.021 | 2.776 | 0.05 | 4 | 66 |
| **Sauger adults (day; Q = 15.3)** | | | | | | |
| Substrate | 6.477 | 8.105 | 2.201 | 0.50 | 11 | 158 |
| Depth | 2.038 | 0.083 | 2.201 | 0.10 | 11 | 41 |
| Velocity | 0.123 | 0.002 | 2.201 | 0.05 | 11 | 4 |
| **Sauger adults (night; Q = 12)** | | | | | | |
| Substrate | 5.050 | 5.925 | 2.262 | 0.50 | 9 | 122 |
| Depth | 1.327 | 0.377 | 2.262 | 0.10 | 9 | 194 |
| Velocity | 0.187 | 0.026 | 2.262 | 0.05 | 9 | 54 |
| **Sauger juveniles (day; Q = 21)** | | | | | | |
| Substrate | 6.075 | 14.343 | 2.776 | 0.50 | 4 | 443 |
| Depth | 1.938 | 0.836 | 2.776 | 0.10 | 4 | 644 |
| Velocity | 0.127 | 0.05 | 2.776 | 0.05 | 4 | 16 |
| **Sauger juveniles (day; Q = 12)** | | | | | | |
| Substrate | 4.754 | 10.007 | 2.082 | 0.50 | 36 | 174 |
| Depth | 1.683 | 0.101 | 2.082 | 0.10 | 36 | 44 |
| Velocity | 0.103 | 0.001 | 2.082 | 0.05 | 36 | 2 |
| **Sauger juveniles (night; Q = 12.3)** | | | | | | |
| Substrate | 5.260 | 4.589 | 2.120 | 0.50 | 16 | 83 |
| Depth | 1.051 | 0.090 | 2.120 | 0.10 | 16 | 41 |
| Velocity | 0.200 | 0.016 | 2.120 | 0.05 | 16 | 29 |

# APPENDIX III

## AN ASSESSMENT OF HABITAT ENHANCEMENT STRUCTURES WHICH ARE UNDER CONSIDERATION FOR PROJECT MITIGATION

# AN ASSESSMENT OF HABITAT ENHANCEMENT STRUCTURES WHICH ARE UNDER CONSIDERATION FOR PROJECT MITIGATION

Data Report
Prepared for:

Alberta Environment
Edmonton, Alberta

Prepared by:

D.A. Fernet, R.F. Courtney and N.E. Barnes
Environmental Management Associates
Calgary, Alberta

May, 1990

# TABLE OF CONTENTS


1.0 INTRODUCTION . . . . . 1

2.0 METHODS . . . . . 2
2.1 PLACEMENT OF HABITAT STRUCTURES . . . . . 6

3.0 RESULTS AND DISCUSSION . . . . . 11
3.1 SCATTERED ROCK . . . . . 11
3.1.1 Rainbow Trout . . . . . 11
3.1.2 Brown Trout . . . . . 14
3.2 ROCK CLUSTERS . . . . . 16
3.2.1 Rainbow Trout . . . . . 16
3.2.2 Brown Trout . . . . . 18
3.3 GROYNES-DEFLECTORS . . . . . 20
3.3.1 Rainbow Trout . . . . . 20
3.3.2 Brown Trout . . . . . 22
3.4 "V" WEIR AND POOL . . . . . 24
3.4.1 Rainbow Trout . . . . . 25
3.4.2 Brown Trout . . . . . 25

4.0 CONCLUSION . . . . . 29

5.0 REFERENCES CITED . . . . . 32

## LIST OF TABLES


| | | PAGE |
|---|---|---|
| TABLE 1 | HABITAT FEATURES WHICH WERE IDENTIFIED AS LIMITING HABITAT SUITABILITY ..... | 3 |
| TABLE 2 | TARGET AMOUNTS OF COVER BY SPECIES AND LIFE STAGE ..... | 4 |
| TABLE 3 | RANGE OF PREFERRED DEPTHS AND VELOCITIES FOR LIFE STAGES UNDER STUDY..... | 10 |
| TABLE 4 | RAINBOW TROUT HABITAT GAINS FOR SCATTERED ROCK GROUPS..... | 12 |
| TABLE 5 | BROWN TROUT HABITAT GAINS FOR SCATTERED ROCK GROUPS..... | 14 |
| TABLE 6 | RAINBOW TROUT HABITAT GAINS FOR ROCK CLUSTERS..... | 17 |
| TABLE 7 | BROWN TROUT HABITAT GAINS FOR ROCK CLUSTERS. | 19 |
| TABLE 8 | RAINBOW TROUT HABITAT GAINS FOR GROYNES..... | 21 |
| TABLE 9 | BROWN TROUT HABITAT GAINS FOR GROYNES..... | 23 |
| TABLE 10 | RAINBOW TROUT HABITAT GAINS FOR "V" WEIR AND POOL..... | 25 |
| TABLE 11 | BROWN TROUT HABITAT GAINS FOR "V" WEIR AND POOL..... | 27 |
| TABLE 12 | MAXIMUM PERCENT INCREASE IN HABITAT FOR THE TOTAL OF ALL STRUCTURES, AND A MEAN VALUE PER STRUCTURE FOR RAINBOW AND BROWN TROUT IN REACHES 4 AND 5..... | 30 |

## LIST OF FIGURES

FIGURE 1 SCATTERED ROCK/CLUSTERS..... 7

FIGURE 2 GROYNES - DEFLECTORS..... 8

FIGURE 3 "V" WEIR AND POOL..... 9

## 1.0 INTRODUCTION

During studies to identify instream flow requirements for rainbow and brown trout downstream of the Oldman River Dam, it was noted that habitat availability was limiting for these species (Fernet et al. 1990). As part of the downstream fisheries mitigation plan, fisheries habitat will be improved by increasing the availability of limiting habitat types. This report presents a quantitative evaluation of several habitat structures developed by the River Engineering Branch of Alberta Environment to overcome habitat limitations downstream of the Oldman River Dam.

## 2.0 METHODS

Environmental Management Associates (EMA) identified habitat types which were limiting habitat suitability downstream of the Oldman River Dam (Table 1). In the care of cover, it was decided that the existing conditions in the Crowsnest and Bow rivers for rainbow trout (Oncorhynchus mykiss) and brown trout (Salmo trutta), respectively, would define the target values for this variable. Habitat characteristics of the Bow and Crowsnest rivers were chosen because of the high quality trout fisheries these watercourses support. The baseline data for these rivers were determined from the habitat preference study conducted by Fernet et al. (1990). The target amounts of cover for each life stage are summarized in Table 2.

The River Engineering Branch of Alberta Environment designed the structures used in the computer habitat simulations. Depth and velocity preference curves for rainbow and brown trout were supplied to River Engineering to aid in locating structures in the study reaches where the life-stage specific preferences could best be accommodated.

Instream Flow Incremental Methodology (IFIM) data decks developed for the Oldman River by EMA (Fernet and Matkowski 1986, 1987) were used to evaluate the proposed habitat structures. River segments 4 and 5 were used for evaluation of the mitigative designs. Study Reach 4 was chosen for detailed analysis because it is the critical segment for fisheries management (Fernet et al. 1990). However, the habitat created by any particular structure is independent of Study Reach characterisitcs. Rather, habitat (weighted usable area) is defined by a combination of existing and created habitat characteristics at the location where a structure is placed.

**TABLE 1**

**HABITAT FEATURES WHICH WERE IDENTIFIED AS LIMITING HABITAT SUITABILITY**

| Species | Life Stage | Habitat Features Required |
|---|---|---|
| Rainbow Trout | Fry | Cover<br>Suitable depths<br>Suitable velocities |
| | Juvenile | Cover<br>Suitable depths |
| | Adult | Cover |
| Brown Trout | Fry | Cover<br>Suitable depths |
| | Juvenile | Cover |
| | Adult | Cover |

**TABLE 2**

**TARGET AMOUNTS OF COVER BY SPECIES AND LIFE STAGE**

| Species | Life Stage | Cover Type | Percent of Reach | Total Perce |
|---|---|---|---|---|
| Rainbow trout | Fry | Instream object | 3.0 | |
| | | offstream overhead | 0.02 | 3.02 |
| | Juvenile | Instream object | 6.0 | 6.0 |
| | Adult | Instream object | 2.0 | 2.0 |
| Brown trout | Fry | Instream object | 20.0 | 20.0 |
| | Juvenile | Instream object | 10.0 | |
| | | Offstream overhead | 0.5 | |
| | | Object plus overhead | 2.0 | 12.5 |
| | Adult | Instream object | 10.0 | |
| | | Offstream object | 0.5 | |
| | | Object plus overhead | 2.0 | 12.5 |

Study Reach 5 was used to compare the habitat gains of the structures in a study reach with different hydraulic characteristics than Study Reach 4. All structures except the "V" weir and pool configuration were tested in Study Reach 5.

Study Reach 4 was modelled at 6 different discharge rates (11, 20, 27, 35, 50 and 65 $m^3/s$). Study Reach 5 was modelled at a representative low, medium and relatively high flow (8, 31 and 50 $m^3/s$) to verify the modelling results from Reach 4. These discharges were chosen to represent the range of discharges which are expected to occur when the Oldman River Dam is operating.

The original IFIM data decks were modified by River Engineering to facilitate the analysis of the habitat structures. River Engineering added a series of duplicate transects and stations on transects to subdivide each study reach into smaller cells. The baseline decks were therefore essentially unchanged from the original IFIM data decks except for the smaller cells. River Engineering then proceeded to incorporate habitat structures into these transects which resulted in changes in the hydraulic characteristics of the cells. Depths, water surface elevations and velocities all changed depending on the structure being modelled. The changes in these parameters were defined and incorporated into the IFIM data decks by River Engineering. The associated quantification and coding of changes in cover for each affected cell in the study reach was subsequently conducted by EMA.

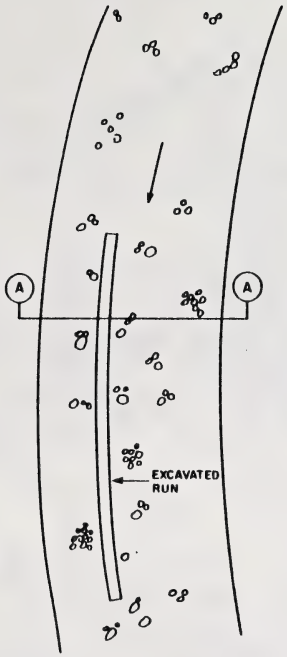
The modified data decks were used to determine habitat gains for the structures in question. Habitat gains were simply the difference in weighted usable area between the data decks with structures and the data decks without structures. Habitat modelling was performed for the adult, juvenile and fry life stages of rainbow and brown trout.

Groups of scattered rocks (cobble patches), rock clusters (boulder gardens), a "V" weir and pool configuration, and groynes were evaluated to determine habitat gains. These structures are illustrated in Figures 1, 2 and 3.

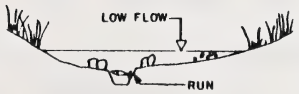
## 2.1 PLACEMENT OF HABITAT STRUCTURES

The location of habitat structures in the river channel has a large influence on the habitat gains that can be expected. To aid placement, the preferred depths and velocities for each life stage were considered (Table 3). The values in Table 3 were determined from the suitability curves presented in Fernet et al. (1990).

The information provided in Table 3 helps determine which areas in a Study Reach would provide the optimal habitat gains for a particular structure. The scattered rock (cobble patches) were designed primarily for the development of nursery habitat. Rock clusters (boulder gardens), groynes and the weir were designed to improve habitat for juveniles and adults. Using the information in Table 3, structures were simulated in areas with the best depths and velocities for the life stages for which they were designed.

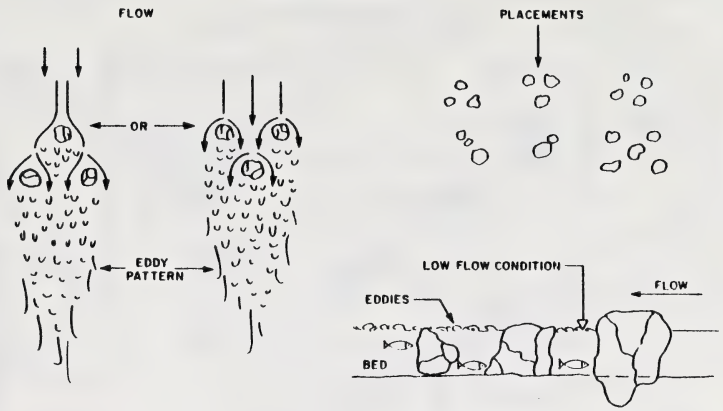



TYPICAL ROCK PLACEMENT



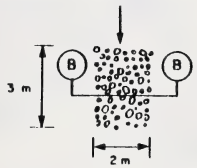

SECTION A-A
TYPICAL CROSS-SECTION

## ROCK CLUSTERS



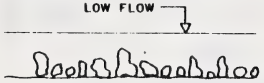

EXCAVATE BELOW BED TO ENSURE ROCK DOES NOT RISE MORE THAN 0.3 m ABOVE WATER SURFACE

## SCATTERED ROCK




15 - 30 PIECES OF SMALL ROCK ($D_{50}$ OR LESS)

ALL ROCK TO SIT ON BED, NONE TOUCHING EACH OTHER




SECTION B-B



ISOMETRIC VIEW

**PURPOSE**
To provide shelter from currents and predators.

**NOTES - Rock Clusters - adult shelter**
1. Rocks may be in clusters of 2, 3, 4 or 5 individual rocks placed in a pattern as shown or directed in the field.
2. Rocks shall be placed at or below, but not to exceed 0.3 m above spring/fall minimum water levels.
3. Rocks shall be spaced at 1.0 - 1.5 m.
4. Only large material from rock classification used - all rocks shall be 0.8 m in size.

**NOTES - Scattered Rock - fry shelter**
1. Scattered rock groups to be used near all spawning sites as much as possible.
2. This grouping is very loose, scattered rock 2 m x 3 m as shown, with rocks close together.
3. All rock to be $D_{50}$ or less in size, placed below existing spring/fall minimum water levels.
4. Rock to be scattered no more than 0.3 m apart, none touching each other.

LIMITING RIVER WIDTH 5 TO 25 m -- flow depth = spring/fall 0.3 m
ARMOR ROCK CLASSIFICATION - 1:100 mean channel velocity

| | CLASS I 3m/s - 10'/s | CLASS II 4m/s - 13'/s | CLASS III 4.7m/s - 15'/s |
|---|---|---|---|
| Dmax | .46m - 13kg/18" - 30Ø | .80m - 700kg/30" -1500Ø | 1.2m - 2300kg/48" - 5000Ø |
| D80 | .35m - 70kg/14" - 150Ø | .60m - 300kg/24" - 700Ø | .90m - 1100kg/36" - 2500Ø |
| D50 | .30m - 40kg/12" - 80Ø | .50m - 200kg/20" - 400Ø | .80m - 750kg/30" - 1500Ø |
| D20 | .20m - 10kg/ 8" - 25Ø | .30m - 10kg/12" - 80Ø | .50m - 200kg/20" - 400Ø |

Alberta Environment

RIVER ENGINEERING BRANCH

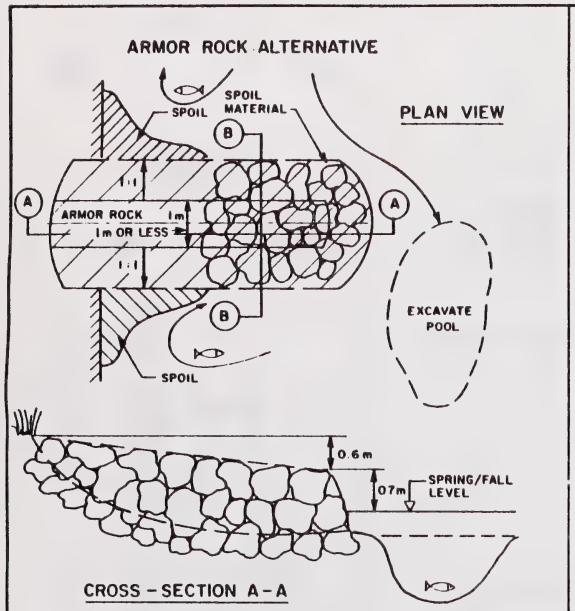
MARCH, 1989

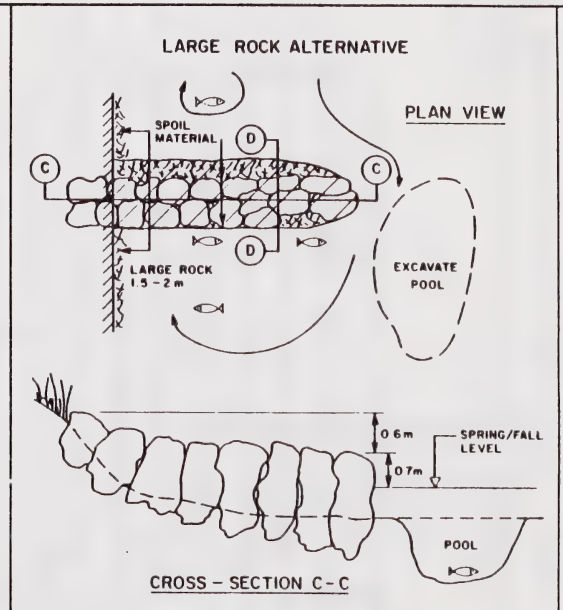
FISH HABITAT IMPROVEMENT

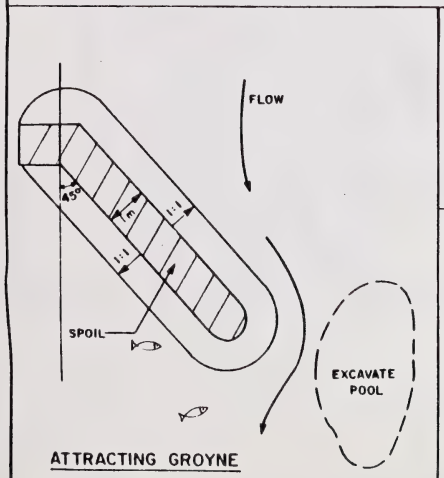
SCATTERED ROCK/CLUSTERS

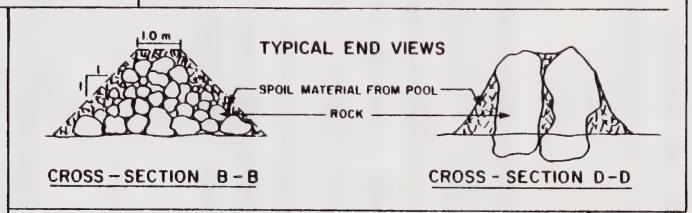
TYPICAL PLAN 2

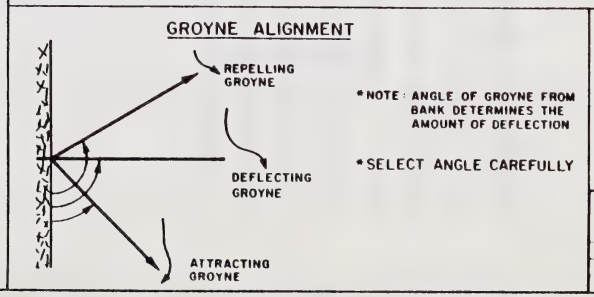
FIGURE No 1




Purpose - to deflect the main current and provide shelter areas and bank protection.

GENERAL NOTES
1. The largest rocks are to be placed at the tip of the groyne. See the rock classification for sizes.
2. Projecting length must not exceed 1/2 river width.
3. The groyne is to be countersunk into the bank.
4. Normally a small run, 2 m wide, 1 m deep and 5 m long is excavated beyond the tip of the groyne to provide a sheltered area.
5. The spoil material from the run is to be placed on the groyne to soften appearances.

REPELLING GROYNES
1. Deflects the main current toward the opposite bank. Heavy armor bank protection is required on the opposite bank.
2. Normally installed on the outside of a bend to deflect the main current awayfrom a downstream eroding bank. This structure will protect eroding banks up to 3.5 times the projecting length.

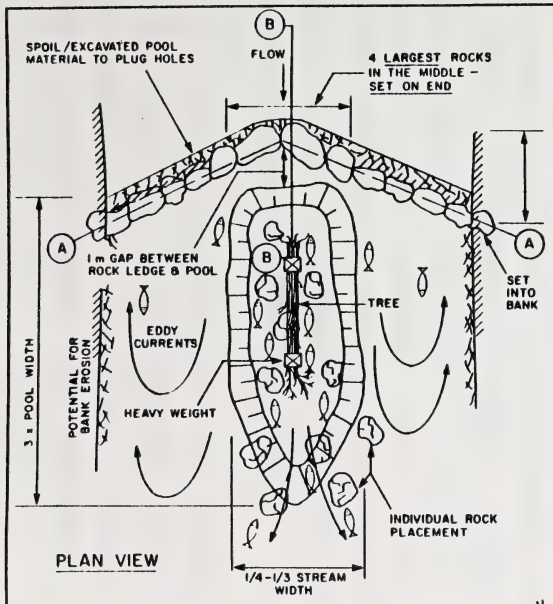
DEFLECTING GROYNES
1. Deflects the main current away from the groyne into mid stream. Opposite bank requires protection when the projection exceeds 1/3 the river width.
2. Normally installed to confine flow to the middle half of a river or deflect flow from an unstable bank on a relatively straight reach.

ATTRACTING GROYNE
1. Deflects the main current a minimum amount, ususally just past the groyne tip.
2. Normally installed in a straight reach to provide meandering flow pattern.

LIMITING RIVER WIDTH 5 TO 25 m -- flow depth * spring/fall 0.3 m
ARMOR ROCK CLASSIFICATION - 1:100 mean channel velocity

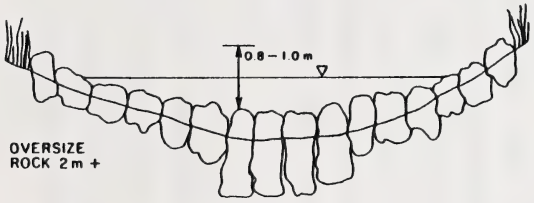
| | CLASS I 3m/s - 10'/s | CLASS II 4m/s - 13'/s | CLASS III 4.7m/s - 15'/s |
|---|---|---|---|
| Dmax | .46m - 13kg/18" - 300# | .80m - 700kg/30" -1500# | 1.2m - 2300kg/48" - 5000# |
| D80 | .35m - 70kg/14" - 150# | .60m - 300kg/24" - 700# | .90m - 1100kg/36" - 2500# |
| D50 | .30m - 40kg/12" - 80# | .50m - 200kg/20" - 400# | .80m - 700kg/30" - 1500# |
| D20 | .20m - 10kg/ 8" - 25# | .30m - 40kg/12" - 80# | .50m - 200kg/20" - 400# |

Alberta ENVIRONMENT
S LOWE
MARCH, 1980
RIVER ENGINEERING BRANCH
FISH HABITAT IMPROVEMENT
GROYNES - DEFLECTORS
TYPICAL PLAN 4
FIGURE No 2

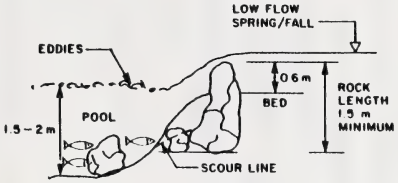




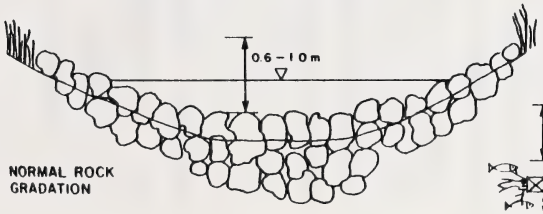


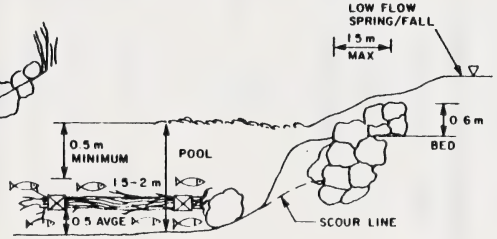



SECTION A-A




SECTION B-B




**PURPOSE** - To provide a self scouring, self maintaining pool, with feeding, resting, and over wintering areas. Rocks in the pool provide cover, isolation from other fish. Rocks at the end of the pool provide feeding opportunities.

**NOTES**

1 - All rocks (Class I, II, III, 2M+) must slope DOWN to the middle of the weir to confine flow in the stream.
2 - All rock must extend downstream from the point (middle) of the weir.
3 - All rocks MUST FIT TIGHTLY TOGETHER. Spoil material may be depositied around the weir (as shown) to plug any voids.
4 - Large rock (2 M+): the four (4) largest rocks must be placed in the middle of the weir and set with the longest side pointing down (as shown). Additional stabilizing rock to be placed at the base of the middle rocks. Pool is then to be excavated.
5 - Normal class rock: Excavate trench, install armor class rock. weir crest length to be no greater than 1.5 m. Pool is then to be excavated.
6 - Excavated material from the pool to be placed on/around wier crest and on downstream banks to control erosion. All other material to be spoiled outside the channel.
7 - Notch on weir must be within the middle third of the stream, but not necessarily in the middle.
8 - The outside edge rocks of the weir shall not be more than 1.0 m above the water level. The notch on the weir shall be 0.6 m above the stream bed.
9 - All elevations relate to low stream flow in fall.
10 - All individual placed rocks to be 0.8 M in size

LIMITING RIVER WIDTH 5 TO 25 m -- flow depth = spring/fall 0.3 m
ARMOR ROCK CLASSIFICATION - 1:100 mean channel velocity

| | CLASS I 3m/s - 10'/s | CLASS II 4m/s - 13'/s | CLASS III 4.7m/s - 15'/s |
|---|---|---|---|
| Dmax | .46m - 13kg/18" - 300# | .80m - 700kg/30" -1500# | 1.2m - 2300kg/48" - 5000# |
| D80 | .35m - 70kg/14" - 150# | .60m - 300kg/24" - 700# | .90m - 1100kg/36" - 2500# |
| D50 | .30m - 40kg/12" - 80# | .50m - 200kg/20" - 400# | .80m - 700kg/30" - 1500# |
| D20 | .20m - 10kg/ 8" - 25# | .30m - 40kg/12" - 80# | .50m - 200kg/20" - 400# |

Alberta Environment | RIVER ENGINEERING BRANCH | S LOWE | NTS | MARCH, 1989

FISH HABITAT IMPROVEMENT

# "V" WEIR & POOL

TYPICAL PLAN 1 | **FIGURE No. 3**

**TABLE 3**

**RANGE OF PREFERRED DEPTHS AND VELOCITIES FOR LIFE STAGES UNDER STUDY**

| Species | Lifestage | Depth (m) | Velocity (m/s) |
|---|---|---|---|
| Brown Trout | Fry | 0.08 - 0.15 | 0.00 - 0.40 |
| | Juvenile | 0.60 - 0.90 | 0.50 - 1.00 |
| | Adult | 0.90 - 1.80 | 0.20 - 0.75 |
| Rainbow Trout | Fry | 0.10 - 0.30 | 0.03 - 0.10 |
| | Juvenile | 0.80 - 1.20 | 0.80 - 1.20 |
| | Adult | >1.00 | 0.20 - 0.50 |

# 3.0 RESULTS AND DISCUSSION

## 3.1 SCATTERED ROCK

Fry habitat was limited by the availability of cover, as well as suitable depths and velocities (Table 1). The clusters of cobble (scattered rock) were intended to improve fry habitat at all discharges. The habitat preferences of fry indicated that the scattered rock should be available in a very narrow range of depths to be usable (Table 3). However, habitat which is suitable at higher discharges is dry at lower river stages. Similarly, suitable habitat at lower discharges is too deep for fry at higher discharges. Scattered rock clusters were simulated in a variety of locations on the river bed so that some patches were in the suitable depth-velocity range at all discharges. As a result, the number of scattered rock groups available for use changed with river stage. A total of 56 patches of scattered rock was used in the simulation.

### 3.1.1 Rainbow Trout

At the lowest discharge rate in Reach 4 (11 $m^3/s$), 9 of the 56 cobble patches were available as cover and gains in habitat (weighted usable area) for rainbow trout fry were as high as 5.10 $m^2$ (Table 4). As the discharge increased, the number of scattered rock patches in the water increased. This resulted in a gradual increase in the habitat gains from 5.10 $m^2$ to 81.26 $m^2$ at the highest discharge. Not only were more patches available, but more patches were available at optimum depths and velocities at the highest discharge rate evaluated.

The target amount of cover for rainbow trout fry was recommended as 3.02 percent of any given Study Reach (Table 2). At low discharges in Study Reach 4, the 9 cobble patches represented a total of 0.44 percent of habitat in the Study Reach (Table 4).

## TABLE 4

## RAINBOW TROUT HABITAT GAINS FOR SCATTERED ROCK GROUPS

| Life Stage | Flow ($m^3/s$) | Study Reach 4 Change in Habitat Per Group ($m^2$) | Study Reach 4 Number of Groups | Study Reach 4 Total Percent of Reach | Study Reach 5 Change in Habitat Per Group ($m^2$) | Study Reach 5 Number of Groups | Study Reach 5 Total Percent of Reach |
|---|---|---|---|---|---|---|---|
| Adult | 8 | -- | -- | -- | 0.00 to 1.46 | 4 | 0.12 |
| | 11 | -0.01 to 0.13 | 9 | 0.00 | -- | -- | -- |
| | 20 | 0.11 to 0.33 | 31 | 0.08 | -- | -- | -- |
| | 27 | 0.00 to 0.20 | 51 | 0.07 | -- | -- | -- |
| | 31 | -- | -- | -- | 0.13 to 1.86 | 5 | 0.14 |
| | 35 | 0.00 to 0.53 | 55 | 0.27 | -- | -- | -- |
| | 50 | 0.23 to 1.65 | 55.5 | 0.82 | 0.06 to 1.84 | 5 | 0.12 |
| | 65 | 0.68 to 3.32 | 56 | 1.63 | -- | -- | -- |
| Juvenile | 8 | -- | -- | -- | 0.00 to 0.38 | 4 | 0.03 |
| | 11 | -0.04 to 0.28 | 9 | 0.00 | -- | -- | -- |
| | 20 | -0.10 to 0.77 | 31 | 0.00 | -- | -- | -- |
| | 27 | 0.00 to 1.54 | 51 | 0.25 | -- | -- | -- |
| | 31 | -- | -- | -- | -0.10 to 1.12 | 5 | 0.00 |
| | 35 | -0.01 to 0.64 | 55 | 0.61 | -- | -- | -- |
| | 50 | -0.03 to 3.93 | 55.5 | 1.80 | -0.43 to 0.17 | 5 | 0.00 |
| | 65 | -0.01 to 4.73 | 56 | 2.12 | -- | -- | -- |
| Fry | 8 | -- | -- | -- | 1.03 to 1.86 | 4 | 0.35 |
| | 11 | 0.00 to 5.10 | 9 | 0.44 | -- | -- | -- |
| | 20 | 3.84 to 9.60 | 31 | 4.40 | -- | -- | -- |
| | 27 | 0.68 to 8.16 | 51 | 4.32 | -- | -- | -- |
| | 31 | -- | -- | -- | 0.20 to 0.81 | 5 | 0.09 |
| | 35 | 6.21 to 10.68 | 55 | 7.25 | -- | -- | -- |
| | 50 | 6.26 to 33.18 | 55.6 | 9.08 | -0.01 to 0.00 | 0 | 0.00 |
| | 65 | 3.31 to 81.26 | 56 | 12.09 | -- | -- | -- |

At the high discharge, the 56 cobble patches which were then available represented a total of 12.09 percent of the Study Reach. From the simulations, it appears that more cobble patches were required at lower discharges and fewer cobble patches are necessary at higher discharges (Table 4). Changing the cobble patch distribution could accomplish this goal.

For the simulations in Study Reach 5, only five cobble patches were modelled in a deep run as opposed to the shallow flats in Study Reach 4 (Table 4). The area containing optimal depths and velocities was quite narrow in Study Reach 5 as the poor habitat gains show. This clearly demonstrates the need for attention to hydraulic characteristics and streambed profiles when placing mitigative structures.

The juvenile and adult life stages of rainbow trout did not benefit from the scattered rock as much as fry in Study Reach 4 (Table 4). Juvenile and adult life stages also showed little gain in habitat from the cobble patches incorporated into Study Reach 5. The scattered rock was designed to improve habitat for the fry life stage, which use the interstitial spaces for cover. These habitat features provided little cover for the larger juvenile or adult life stages.

### 3.1.2 Brown Trout

Only 9 of the 56 cobble patches were available as cover in Study Reach 4 at the lowest discharge (11 $m^3/s$), as previously noted. Gains in habitat for brown trout fry were as high as 25.98 $m^2$ at this discharge rate (Table 5). As the discharge and number of items increased, habitat gains were as high as 40.93 $m^2$. At the lower discharges, this gain is over five times as great as that predicted for rainbow trout, while at the higher discharges, the gain in habitat is less than half that realized for rainbow trout fry (Table 4). These differences are a result of the preference of

## TABLE 5

## BROWN TROUT HABITAT GAINS FOR SCATTERED ROCK GROUPS

| Life Stage | Flow ($m^3/s$) | Study Reach 4 | | | Study Reach 5 | | |
|---|---|---|---|---|---|---|---|
| | | Change in Habitat Per Group ($m^2$) | Number of Groups | Total Percent of Reach | Change in Habitat Per Group ($m^2$) | Number of Groups | Total Percent of Reach |
| Adult | 8 | -- | -- | -- | 0.03 to 1.43 | 4 | 0.10 |
| | 11 | -0.25 to 0.73 | 9 | 0.02 | -- | -- | -- |
| | 20 | 0.28 to 0.94 | 31 | 0.25 | -- | -- | -- |
| | 27 | 0.08 to 0.66 | 51 | 0.44 | -- | -- | -- |
| | 31 | -- | -- | -- | 0.87 to 7.33 | 5 | 0.62 |
| | 35 | 0.20 to 1.67 | 55 | 0.93 | -- | -- | -- |
| | 50 | 0.61 to 2.46 | 55 | 1.29 | -0.98 to 9.84 | 5 | 0.45 |
| | 65 | 1.32 to 4.44 | 56 | 2.31 | -- | -- | -- |
| Juvenile | 8 | -- | -- | -- | 0.00 to 0.74 | 4 | 0.05 |
| | 11 | -0.63 to 1.73 | 9 | 0.00 | -- | -- | -- |
| | 20 | -0.22 to 1.78 | 31 | 0.00 | -- | -- | -- |
| | 27 | 0.03 to 1.33 | 51 | 0.85 | -- | -- | -- |
| | 31 | -- | -- | -- | 0.29 to 0.43 | 5 | 0.08 |
| | 35 | 0.17 to 4.16 | 55 | 2.19 | -- | -- | -- |
| | 50 | 0.61 to 5.38 | 55.5 | 2.62 | 0.17 to 1.47 | 5 | 0.11 |
| | 65 | -0.001 to 4.52 | 56 | 2.15 | -- | -- | -- |
| Fry | 8 | -- | -- | -- | 0.32 to 1.76 | 4 | 0.20 |
| | 11 | 0.02 to 25.98 | 9 | 2.45 | -- | -- | -- |
| | 20 | 2.50 to 10.43 | 31 | 4.62 | -- | -- | -- |
| | 27 | 0.06 to 11.60 | 51 | 4.37 | -- | -- | -- |
| | 31 | -- | -- | -- | 0.07 to 0.74 | 5 | 0.06 |
| | 35 | 8.51 to 11.46 | 55 | 7.61 | -- | -- | -- |
| | 50 | 3.87 to 40.40 | 55.5 | 7.35 | 0.00 | 5 | 0.00 |
| | 65 | 0.18 to 40.93 | 56 | 5.21 | -- | -- | -- |

brown trout fry for shallower water compared to rainbow trout fry (Table 3). The shallow water was increasingly available at lower discharges.

The target amount of cover for brown trout fry is 20 percent of the Study Reach (Table 2). However the highest percentage obtained in Study Reach 4 was 7.61 percent (Table 5), which occurred at the mid-range discharge (35 $m^3/s$). Therefore, more cobble patches would be required to achieve target cover percentages for brown trout fry. The 20 percent target level may exceed the requirements for brown trout fry. However, without further information on the actual requirements for brown trout fry, 20 percent remains the best estimate of required cover for quality habitat.

The gains in habitat for brown trout fry in Study Reach 5 were similar to those of Study Reach 4 for the same reasons. At the lower discharges, gains were as high as 1.76 $m^2$, with the cobble patches representing 0.20 percent of the Study Reach (Table 5). At the highest discharge modelled (50 $m^3/s$), there were no gains in habitat. The cobble patches were at unsuitable depths and/or velocities to provide brown trout fry habitat.

Juvenile and adult brown trout receive little benefit from this habitat enhancement technique.

Scattered rock was most effective for generating fry cover when placed in areas with a gradual shoreline gradient. Steep shoreline gradients should be avoided. Scattered rock should be provided at a variety of elevations on the streambed so that some patches will be available to fry in the suitable depth range (0.08-0.30 m) at all discharges.

## 3.2 ROCK CLUSTERS

Rock clusters were designed primarily to improve habitat for the adult life stage. Boulders were placed in areas with optimal depths and velocities for adults at a wide range of discharges. In each Study Reach, boulders were arranged into two groups: one with three boulders; and, one with four boulders. All rock clusters were available to fish at all simulated discharges.

### 3.2.1 Rainbow Trout

Rainbow trout fry showed very little gain in habitat from the boulder groupings at any flow (Table 6). The rock clusters were placed at depths and velocities that were unsuitable for use by fry. Fry often showed a slight loss of habitat after boulders were placed in the Study Reach due to changes in the hydraulic characteristics. Study Reach 5 showed essentially the same pattern as Study Reach 4.

Very little benefit for rainbow trout juveniles was predicted from the installation of rock clusters at all flows in both study reaches (Table 6). Placement in areas of ideal depths and velocities for this life stage would improve habitat gains for juveniles.

Rainbow trout adults showed good gains in habitat from the use of rock clusters (Table 6). Although only 2 boulder clusters were used, adults gained up to 49.93 $m^2$ of habitat in Study Reach 4 and 23.73 $m^2$ in Study Reach 5. Gains were good at all modelled flows except 8 $m^3/s$ in Study Reach 5. There was a maximum predicted increase in habitat of 0.92 percent in Study Reach 4, which is approximately half the target of 2.0 percent (Table 2). Gains were highest for the mid-range flows.

## TABLE 6

## RAINBOW TROUT HABITAT GAINS FOR ROCK CLUSTERS

| Life Stage | Flow ($m^3/s$) | Study Reach 4 | | | Study Reach 5 | | |
|---|---|---|---|---|---|---|---|
| | | Change in Habitat Per Group ($m^2$) | Number of Clusters | Total Percent of Reach | Change in Habitat Per Group ($m^2$) | Number of Clusters | Total Percent of Reach |
| Adult | 8 | -- | -- | - | 0.37 to 4.90 | 2 | 0.08 |
| | 11 | 2.35 to 23.29 | 2 | 0.55 | -- | -- | -- |
| | 20 | 7.04 to 45.24 | 2 | 0.92 | -- | -- | -- |
| | 27 | 6.23 to 49.93 | 2 | 0.90 | -- | -- | -- |
| | 31 | -- | -- | -- | 13.62 to 22.26 | 2 | 0.45 |
| | 35 | 5.30 to 36.87 | 2 | 0.63 | -- | -- | -- |
| | 50 | 4.08 to 31.85 | 2 | 0.47 | 12.91 to 23.73 | 2 | 0.43 |
| | 65 | 11.09 TO 31.85 | 2 | 0.46 | -- | -- | -- |
| Juvenile | 8 | -- | -- | -- | 1.02 to 1.14 | 2 | 0.03 |
| | 11 | -0.27 to 2.81 | 2 | 0.05 | -- | -- | -- |
| | 20 | 1.46 to 6.30 | 2 | 0.14 | -- | -- | -- |
| | 27 | -11.65 to 1.91 | 2 | 0.00 | -- | -- | -- |
| | 31 | -- | -- | -- | 2.95 to 7.31 | 2 | 0.13 |
| | 35 | 0.52 to 1.32 | 2 | 0.03 | -- | -- | -- |
| | 50 | -0.01 to 0.91 | 2 | 0.01 | 2.44 to 3.83 | 2 | 0.19 |
| | 65 | 0.18 to 0.33 | 2 | 0.01 | -- | -- | -- |
| Fry | 8 | -- | -- | -- | 0.07 to 0.04 | 2 | 0.00 |
| | 11 | -0.02 to 0.06 | 2 | 0.00 | -- | -- | -- |
| | 20 | -0.08 to 0.13 | 2 | 0.00 | -- | -- | -- |
| | 27 | -0.67 to 0.53 | 2 | 0.00 | -- | -- | -- |
| | 31 | -- | -- | -- | 0.50 to 0.08 | 2 | 0.01 |
| | 35 | -0.82 to 0.00 | 2 | 0.00 | -- | -- | -- |
| | 50 | -0.69 to -0.10 | 2 | 0.00 | -0.06 to 0.01 | 2 | 0.00 |
| | 65 | -0.05 to 0.04 | 2 | 0.00 | -- | -- | -- |

### 3.2.2 Brown Trout

There were no gains in habitat for brown trout fry due to the installation of rock clusters in either Study Reach (Table 7). Once again, the placement of the rock clusters to benefit adult trout precluded any benefit for fry.

Brown trout juveniles experienced moderate to good gains in habitat from the boulder groupings in both Study reaches (Table 7). Habitat gains were substantially better than that predicted for rainbow trout juveniles. Gains were as high as 28.95 $m^2$ in Study Reach 4 and 24.78 $m^2$ in Study Reach 5. Increases in juvenile habitat reached maximum percentages of 0.52 in Study Reach 4 and 0.34 percent in Study Reach 5, which is less than the 12.5 percent target value for this life stage (Table 2). Further increases in habitat gains would result from increasing the number of boulder clusters installed.

Brown trout adults experienced very good gains in habitat from the rock clusters (Table 7). Habitat gains were as high as 112.42 $m^2$ in Study Reach 4. Habitat gains in Study Reach 5 were somewhat lower with a maximum gain of 25.68 $m^2$. Percentage increases were as high as 2.08 percent in Study Reach 4 and 0.51 percent in Study Reach 5. The target cover value for brown trout adults is 12.5 percent (Table 2).

Overall, the rock clusters provided good habitat gains for both brown and rainbow adult life stages. Only two groups of boulders were used in each Study Reach, yet habitat gains were considerable. Brown trout juveniles also showed moderate to good gains in habitat. Fry showed no increase in habitat from rock clusters.

## TABLE 7

## BROWN TROUT HABITAT GAINS FOR ROCK CLUSTERS

| Life Stage | Flow ($m^3/s$) | Study Reach 4 | | | Study Reach 5 | | |
|---|---|---|---|---|---|---|---|
| | | Change in Habitat Per Group ($m^2$) | Number of Clusters | Total Percent of Reach | Change in Habitat Per Group ($m^2$) | Number of Clusters | Total Percent of Reach |
| Adult | 8 | -- | -- | - | 4.54 to 6.86 | 2 | 0.18 |
| | 11 | 0.03 to 20.76 | 2 | 0.45 | -- | -- | -- |
| | 20 | 11.76 to 89.62 | 2 | 1.78 | -- | -- | -- |
| | 27 | 17.11 to 112.42 | 2 | 2.08 | -- | -- | -- |
| | 31 | -- | -- | -- | 15.06 to 21.79 | 2 | 0.48 |
| | 35 | 10.25 to 26.94 | 2 | 0.55 | -- | -- | -- |
| | 50 | 5.08 to 33.36 | 2 | 0.51 | 14.92 to 25.68 | 2 | 0.51 |
| | 65 | 42.06 to 57.60 | 2 | 1.23 | -- | -- | -- |
| Juvenile | 8 | -- | -- | -- | 4.44 to 6.61 | 2 | 0.17 |
| | 11 | -4.57 to 2.85 | 2 | 0.00 | -- | -- | -- |
| | 20 | 4.90 to 24.66 | 2 | 0.52 | -- | -- | -- |
| | 27 | -33.76 to 7.78 | 2 | 0.00 | -- | -- | -- |
| | 31 | -- | -- | -- | 3.66 to 22.59 | 2 | 0.34 |
| | 35 | 1.37 to 7.48 | 2 | 0.13 | -- | -- | -- |
| | 50 | 3.27 to 8.16 | 2 | 0.15 | 1.78 to 24.78 | 2 | 0.33 |
| | 65 | 5.65 to 28.95 | 2 | 0.43 | -- | -- | -- |
| Fry | 8 | -- | -- | -- | 0.00 | 2 | 0.00 |
| | 11 | 0.00 | 2 | 0.00 | -- | -- | -- |
| | 20 | 0.00 | 2 | 0.00 | -- | -- | -- |
| | 27 | 0.00 | 2 | 0.00 | -- | -- | -- |
| | 31 | -- | -- | -- | 0.00 | 2 | 0.00 |
| | 35 | 0.00 | 2 | 0.00 | -- | -- | -- |
| | 50 | 0.00 | 2 | 0.00 | 0.00 | 2 | 0.00 |
| | 65 | 0.00 | 2 | 0.00 | -- | -- | -- |

## 3.3 GROYNES-DEFLECTORS

Five groynes were incorporated into both the Study Reach 4 and Study Reach 5 data decks for evaluation of the effects on habitat availability. Some groynes provided better habitat at low discharges, while others increased habitat availability at high discharges. Results from both reaches were similar.

### 3.3.1 Rainbow Trout

Rainbow trout fry in Study Reach 4 had gains in habitat as high as 23.98 $m^2$ at the lowest discharges (11 $m^3/s$) and as high as 41.63 $m^2$ at the highest discharges modelled (65 $m^3/s$). The gains did not achieve the target percentage of cover (3.02%) for any discharge (Table 8).

Habitat gains for rainbow trout fry in Study Reach 5 were similar to those for Study Reach 4 (Table 8). The groyne producing the greatest gain in habitat for fry was located in a shallow, flat area, which resulted in many areas of optimal depth and velocity. The fry may also utilize the interstitial spaces of the riprap for cover. At higher discharges in Study Reach 5, the groynes resulted in 2.56 percent usable habitat for rainbow trout fry, which is close to the target value of 3.02 percent (Table 2).

Rainbow trout juveniles also experienced significant gains in usable habitat with groyne creation. However, like the fry life stage, increases are lowest at the mid-range discharges. At the lower discharges in Reach 4 (20 $m^3/s$), habitat gains are as high as 11.02 $m^2$. At the higher discharges (50 $m^3/s$), maximum predicted gains are 16.16 $m^3$ (Table 8). At the higher discharge value, 0.66 percent of the Study Reach provided cover for juveniles, which is less than the 6.0 percent target value (Table 2). Groynes in Study Reach 5 generally resulted in greater habitat gains than Study Reach 4 (Table 8). The peak value of 0.92

## TABLE 8

## RAINBOW TROUT HABITAT GAINS FOR GROYNES

| Life Stage | Flow ($m^3/s$) | Study Reach 4 Change in Habitat Per Group ($m^2$) | Study Reach 4 Number of Groynes | Study Reach 4 Total Percent of Reach | Study Reach 5 Change in Habitat Per Group ($m^2$) | Study Reach 5 Number of Groynes | Study Reach 5 Total Percent of Reach |
|---|---|---|---|---|---|---|---|
| Adult | 8 | -- | -- | - | -0.17 to 4.46 | 5 | 0.18 |
| | 11 | -0.04 to 40.49 | 5 | 0.63 | -- | -- | -- |
| | 20 | -1.33 to 46.58 | 5 | 1.24 | -- | -- | -- |
| | 27 | 0.71 to 49.55 | 5 | 1.52 | -- | -- | -- |
| | 31 | -- | -- | -- | 3.97 to 14.07 | 5 | 0.73 |
| | 35 | 5.18 to 53.36 | 5 | 1.83 | -- | -- | -- |
| | 50 | 11.39 to 55.03 | 5 | 1.87 | 4.88 to 11.86 | 5 | 0.61 |
| | 65 | 19.28 to 57.87 | 5 | 2.07 | -- | -- | -- |
| Juvenile | 8 | -- | -- | -- | 0.18 to 2.55 | 5 | 0.11 |
| | 11 | 0.09 to 6.23 | 5 | 0.26 | -- | -- | -- |
| | 20 | -0.19 to 11.02 | 5 | 0.55 | -- | -- | -- |
| | 27 | 2.85 to 10.63 | 5 | 0.49 | -- | -- | -- |
| | 31 | -- | -- | -- | 3.79 to 22.17 | 5 | 0.92 |
| | 35 | 6.15 to 7.94 | 5 | 0.53 | -- | -- | -- |
| | 50 | 1.71 to 16.16 | 5 | 0.66 | 5.89 to 17.81 | 5 | 0.92 |
| | 65 | 1.31 to 15.41 | 5 | 0.57 | -- | -- | -- |
| Fry | 8 | -- | -- | -- | 1.00 to 31.39 | 5 | 0.81 |
| | 11 | 4.59 to 23.98 | 5 | 1.71 | -- | -- | -- |
| | 20 | 6.85 to 10.54 | 5 | 0.80 | -- | -- | -- |
| | 27 | 1.64 to 5.92 | 5 | 0.32 | -- | -- | -- |
| | 31 | -- | -- | -- | 0.13 to 23.88 | 5 | 0.40 |
| | 35 | 2.51 to 9.33 | 5 | 0.42 | -- | -- | -- |
| | 50 | 3.03 to 4.71 | 5 | 0.26 | 1.19 to 141.87 | 5 | 2.56 |
| | 65 | 3.59 to 41.63 | 5 | 1.32 | -- | -- | -- |

percent for Study Reach 5 was also lower than the target value of 6.0 percent.

In Study Reach 4, habitat gains for the groynes were greatest for rainbow trout adults. There was a gradual increase from a high of 40.49 $m^2$ at the low discharge (11 $m^3/s$) to 57.87 $m^2$ at the high discharge (65 $m^3/s$) (Table 8). The highest discharge resulted in 2.07 percent of the Study Reach providing cover due to the 5 groynes. This value exceeded the 2.0 percent target value for adults (Table 2). Habitat gains for adults in Study Reach 5 were somewhat lower than Study Reach 4, with a maximum gain in usable habitat of 0.73 percent of the Study Reach (Table 8).

### 3.3.2 Brown Trout

Brown trout fry in Study Reach 4 experienced gains in habitat as high as 16.46 $m^2$ at 11 $m^3/s$ and 54.30 $m^2$ at 65 $m^3/s$ with the use of groynes. These gains represent a total of 1.12 and 1.39 percent, respectively, of the Study Reach (Table 9). This was somewhat less than the 20.0 percent target value (Table 2). As with rainbow trout fry, habitat gains were less in the mid-range discharges. Much of the cover at the high discharge was provided by the interstitial spaces within the riprap on the groynes.

Brown trout fry habitat gains in Study Reach 5 were greater than those for Study Reach 4, especially at 50 $m^3/s$ (Table 9). Brown trout fry gain somewhat less cover at the higher discharge than rainbow trout fry due to their narrower range of preferred depths. Habitat gains were as high as 15.79 $m^2$ at 8 $m^3/s$ and as high as 73.66 $m^2$ at 50 $m^3/s$ (Table 9). At this higher discharge, the groynes produced cover for 1.60 percent of the Study Reach. This value is considerably less than the 20.0 percent target value for this life stage (Table 2).

## TABLE 9

## BROWN TROUT HABITAT GAINS FOR GROYNES

| Life Stage | Flow ($m^3/s$) | Study Reach 4 | | | Study Reach 5 | | |
|---|---|---|---|---|---|---|---|
| | | Change in Habitat Per Group ($m^2$) | Number of Groynes | Total Percent of Reach | Change in Habitat Per Group ($m^2$) | Number of Groynes | Total Percent of Reach |
| Adult | 8 | -- | -- | - | 0.82 to 3.24 | 5 | 0.17 |
| | 11 | 3.73 to 8.99 | 5 | 0.69 | -- | -- | -- |
| | 20 | -1.75 to 20.10 | 5 | 0.74 | -- | -- | -- |
| | 27 | -5.67 to 23.56 | 5 | 0.77 | -- | -- | -- |
| | 31 | -- | -- | -- | -4.34 to 15.56 | 5 | 0.61 |
| | 35 | -2.75 to 18.68 | 5 | 0.75 | -- | -- | -- |
| | 50 | -23.47 to 19.79 | 5 | 0.05 | 1.99 to 22.42 | 5 | 0.63 |
| | 65 | 3.77 to 26.01 | 5 | 0.89 | -- | -- | -- |
| Juvenile | 8 | -- | -- | -- | 0.41 to 7.80 | 5 | 0.34 |
| | 11 | 7.61 to 21.70 | 5 | 1.36 | -- | -- | -- |
| | 20 | 9.03 to 16.54 | 5 | 1.09 | -- | -- | -- |
| | 27 | 7.59 to 19.66 | 5 | 1.07 | -- | -- | -- |
| | 31 | -- | -- | -- | -6.33 to 14.14 | 5 | 0.16 |
| | 35 | -2.81 to 23.20 | 5 | 0.16 | -- | -- | -- |
| | 50 | -1.96 to 19.73 | 5 | 0.20 | -23.40 to 31.90 | 5 | 0.00 |
| | 65 | 0.27 to 5.63 | 5 | 1.51 | -- | -- | -- |
| Fry | 8 | -- | -- | -- | 1.02 to 15.79 | 5 | 0.42 |
| | 11 | 3.64 to 16.46 | 5 | 1.12 | -- | -- | -- |
| | 20 | 2.71 to 5.82 | 5 | 0.40 | -- | -- | -- |
| | 27 | 0.002 to 4.53 | 5 | 0.26 | -- | -- | -- |
| | 31 | -- | -- | -- | 0.03 to 22.28 | 5 | 0.37 |
| | 35 | 0.00 to 6.39 | 5 | 0.29 | -- | -- | -- |
| | 50 | 1.37 to 2.28 | 5 | 0.13 | 2.69 to 73.66 | 5 | 1.60 |
| | 65 | 0.29 to 54.30 | 5 | 1.39 | -- | -- | -- |

Brown trout juveniles experienced habitat gains of up to 23.2 $m^2$ (Table 9). Gains in habitat exceeded 1 percent of the Study Reach except at 35 and 50 $m^3/s$. Habitat gains for brown trout juveniles were greater than those for rainbow trout juveniles, but were substantially below the 12.5 percent target value (Table 2). Habitat gains for Study Reach 5 were comparable, but lower than those experienced in Study Reach 4.

Habitat gains for brown trout adults realized with the installation of groynes were as high as 26.01 $m^2$ (Table 9). This resulted in a maximum habitat increase of 0.89 percent of the Study Reach. These values are somewhat lower than those computed for rainbow trout adults (Table 8). The target value for brown trout adults was 12.5 percent (Table 2). Habitat gains in Study Reach 5 were similar to those for Study Reach 4.

The groynes produced increased habitat for all life stages. Groynes are valuable because they create a wide variety of depths and velocities at any given discharge, increasing habitat diversity. Large cobble and boulders should be used for rip-rap on the groynes to improve their cover characteristics for trout. Results from both study reaches were comparable, demonstrating that groynes were less sensitive to shoreline gradient than scattered rock.

### 3.4 "V" WEIR AND POOL

A V-shaped weir and pool (Figure 3) was simulated in Study Reach 4 only. Use of the weir/pool structure is restricted to side channels of the Oldman River. The river is too large and wide to allow use of this structure on the mainstem river without considerable cost and potential impacts on other channel characteristics.

### 3.4.1 Rainbow Trout

The V-shaped weir and pool complex provided only minimal gains in habitat for rainbow trout fry. The complex added little cover where suitable depths and velocities existed for this life stage. The highest gain in habitat was 0.74 $m^2$ which occurred at 35 $m^3/s$ (Table 10).

Rainbow trout juveniles experience more substantial gains in habitat at the weir-pool complex. The maximum habitat gain was 11.0 $m^2$ which occurred at a discharge of 50 $m^3/s$ (Table 10). This value represents 0.15 percent of the Study Reach, which is less than the 6.0 percent target value.

Rainbow trout adults experienced good gains in habitat for the weir-pool complex at all discharges except the 11 $m^3/s$ (Table 10). At this discharge rate, there was virtually no water flowing over the weir. Habitat gains were consistently high at all other discharges, with the highest gain at 35 $m^3/s$, at which the weir-pool complex provided cover for 0.57 percent of the Study Reach. The weir-pool complex provided good habitat but only for a small area within the total Study Reach.

### 3.4.2 Brown Trout

Brown trout fry experienced little improvement in habitat from the weir-pool complex, with a maximum gain of 0.6 $m^2$ at 35 $m^3/s$ (Table 11). This value represents only 0.01 percent of the total habitat available in the Study Reach.

Brown trout juveniles had good gains in habitat for the weir-pool complex (Table 11), which were significantly more than those for rainbow trout juveniles. This is a result of their preference for overhead cover, and the fact that brown trout juveniles prefer shallower, slower-flowing water (Table 3). Gains

## TABLE 10

## RAINBOW TROUT HABITAT GAINS FOR "V" WEIR AND POOL

| Flow ($m^3/s$) | Study Reach Area ($m^2$) | Adults | | Juveniles | | Fry | |
|---|---|---|---|---|---|---|---|
| | | Habitat Gain ($m^2$) | Total Percent of Study Reach | Habitat Gain ($m^2$) | Total Percent of Study Reach | Habitat Gain ($m^2$) | Total Percent of Study Reach |
| 11 | 4650.72 | 0.13 | 0.00 | 0.45 | 0.01 | -0.07 | 0.00 |
| 20 | 5709.32 | 26.06 | 0.46 | 3.27 | 0.06 | 0.26 | 0.01 |
| 27 | 6226.54 | 33.98 | 0.55 | 6.72 | 0.11 | 0.28 | 0.01 |
| 35 | 6715.60 | 38.10 | 0.57 | 8.94 | 0.13 | 0.74 | 0.01 |
| 50 | 7588.13 | 37.92 | 0.50 | 11.00 | 0.15 | -0.41 | 0.00 |
| 65 | 8088.16 | 33.05 | 0.41 | 5.70 | 0.07 | -0.21 | 0.00 |

## TABLE 11

## BROWN TROUT HABITAT GAINS FOR "V" WEIR AND POOL

| Flow ($m^3/s$) | Study Reach Area ($m^2$) | Adults | | Juveniles | | Fry | |
|---|---|---|---|---|---|---|---|
| | | Habitat Gain ($m^3$) | Total Percent of Study Reach | Habitat Gain ($m^3$) | Total Percent of Study Reach | Habitat Gain ($m^3$) | Total Percent of Study Reach |
| 11 | 4650.72 | 0.86 | 0.02 | 3.12 | 0.10 | 0.00 | 0.00 |
| 20 | 5709.32 | 56.58 | 0.99 | 21.16 | 0.49 | 0.00 | 0.00 |
| 27 | 6226.54 | 75.06 | 1.32 | 44.15 | 0.97 | 0.01 | 0.00 |
| 35 | 6715.60 | 77.48 | 1.15 | 44.88 | 0.67 | 0.60 | 0.01 |
| 50 | 7588.13 | 65.19 | 0.86 | 30.25 | 0.40 | 0.00 | 0.00 |
| 65 | 8088.16 | 46.36 | 0.57 | 13.15 | 0.16 | 0.00 | 0.00 |

for juveniles were as high as 44.88 $m^2$ at 35 $m^3/s$ (Table 11). This value represents 0.67 percent of the Study Reach.

Brown trout adults also had excellent gains in habitat from the weir-pool complex, with a maximum increase of 77.48 $m^2$ at 35 $m^3/s$ (Table 11). This value represents 1.15 percent of the Study Reach, which is less than the 12.5 percent target value for this life stage (Table 2).

The weir-pool complex provided good habitat for juveniles and adults. This structure provided poor habitat for fry, and is limited to use in side channels of the Oldman River.

## 4.0 CONCLUSION

The target values for cover presented in Table 2 provided a guideline for this investigation. However, it is not known when cover becomes limiting for either rainbow or brown trout. It is known that the Bow River and the Crowsnest River are very productive brown and rainbow trout fisheries. Therefore, these rivers were used to provide the target cover values. These values may, however, exceed the requirements of the trout for cover. As a result, the target values presented in this report should simply be treated as guidelines. Clearly, all target values for cover can be met if enough structures were constructed. However, this may not be feasible and may be unnecessary to develop a quality trout fishery in the Oldman River downstream of the dam.

Evaluation of the enhancement structures must consider cost. In order to properly assess the benefit/cost ratio of the prospective mitigative structures, it is necessary to know just how much habitat is created per structure.

Table 12 presents the maximum increase in habitat per structure, for both study reaches and all life stages. For example, it can be seen that scattered rock and groynes provide the greatest percent increase in habitat per structure for rainbow trout fry. However, groyne construction would be more expensive than a single patch of cobble (scattered rock). Therefore scattered rock would be the better choice for improving fry habitat in a cost-effective manner.

It appears that a combination of structures will provide the best habitat improvement for all life stages. Scattered rock and rock clusters provide some of the best habitat gains per structural unit. The scattered rock provides habitat for fry while

TABLE 12

MAXIMUM PERCENT INCREASE IN HABITAT FOR THE TOTAL OF ALL STRUCTURES, AND A MEAN VALUE PER STRUCTURE FOR RAINBOW AND BROWN TROUT IN REACHES 4 AND 5

**STUDY REACH 4**

| SPECIES | LIFESTAGE | SCATTERED ROCK | | ROCK CLUSTERS | | GROYNES | | V-WEIR AND POOL | | TARGET AMOUNT |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Total Increases | Per Unit | Total Increases | Per Unit | Total Increases | Per Unit | Total Increases | Per Unit | Percent Cover |
| Rainbow Trout | Fry | 12.09 | 0.22 | 0.00 | 0.00 | 1.71 | 0.34 | 0.01 | 0.01 | 3.02 |
| | Juvenile | 2.12 | 0.04 | 0.14 | 0.07 | 0.66 | 0.13 | 0.15 | 0.15 | 6.0 |
| | Adult | 1.63 | 0.03 | 0.92 | 0.46 | 2.07 | 0.41 | 0.57 | 0.57 | 2.0 |
| Brown Trout | Fry | 7.61 | 0.14 | 0.00 | 0.00 | 1.39 | 0.28 | 0.01 | 0.012 | 0.0 |
| | Juvenile | 2.62 | 0.05 | 0.52 | 0.26 | 1.51 | 0.30 | 0.97 | 0.971 | 2.5 |
| | Adult | 2.31 | 0.04 | 1.78 | 0.89 | 0.89 | 0.18 | 1.32 | 1.321 | 2.5 |

**STUDY REACH 5**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rainbow Trout | Fry | 0.35 | 0.08 | 0.01 | 0.005 | 2.56 | 0.51 | -- | -- | 3.02 |
| | Juvenile | 0.03 | 0.01 | 0.19 | 0.09 | 0.92 | 0.18 | -- | -- | 6.0 |
| | Adult | 0.14 | 0.03 | 0.45 | 0.22 | 0.73 | 0.15 | -- | -- | 2.0 |
| Brown Trout | Fry | 0.20 | 0.05 | 0.00 | 0.00 | 1.60 | 0.32 | -- | -- | 20.0 |
| | Juvenile | 0.11 | 0.02 | 0.34 | 0.17 | 0.34 | 0.07 | -- | -- | 12.5 |
| | Adult | 0.62 | 0.12 | 0.51 | 0.25 | 0.63 | 0.13 | -- | -- | 12.5 |

the rock clusters provide habitat for juvenile and adult life stages. Groynes provide moderate levels of habitat improvement for the life stages of most species and are good for fry. The V-weir and pool provide good habitat for adults and juveniles, but little habitat for fry. It is important to note that no single enhancement structure provides the best habitat gains for all species and life stages.

## 5.0 REFERENCES CITED

Fernet, D.A., R.F. Courtney, and C.P. Bjornson. 1990. Instream flow requirements for fishes downstream of the Oldman River Dam. Memo Report prepared for Alberta Public Works, Supply and Services, Edmonton, Alberta. 129+ pp.

Fernet, D.A. and S.M. Matkowski. 1986. Oldman River Dam environmental mitigation/opportunities plan instream flow study. Fish distribution, abundance, critical habitats and relationships with streamflow downstream of the Oldman River Damsite. Prepared for Planning Division, Alberta Environment. 137+ pp.

Fernet, D.A. and S.M. Matkowski. 1987. Relationships between habitat availability and discharge for selected fish species downstream of the proposed Oldman River Dam. Prepared for Planning Division, Alberta Environment. 59 pp.

# APPENDIX IV

## DATA SETS USED IN THE DEVELOPMENT OF HABITAT PREFERENCE CRITERIA

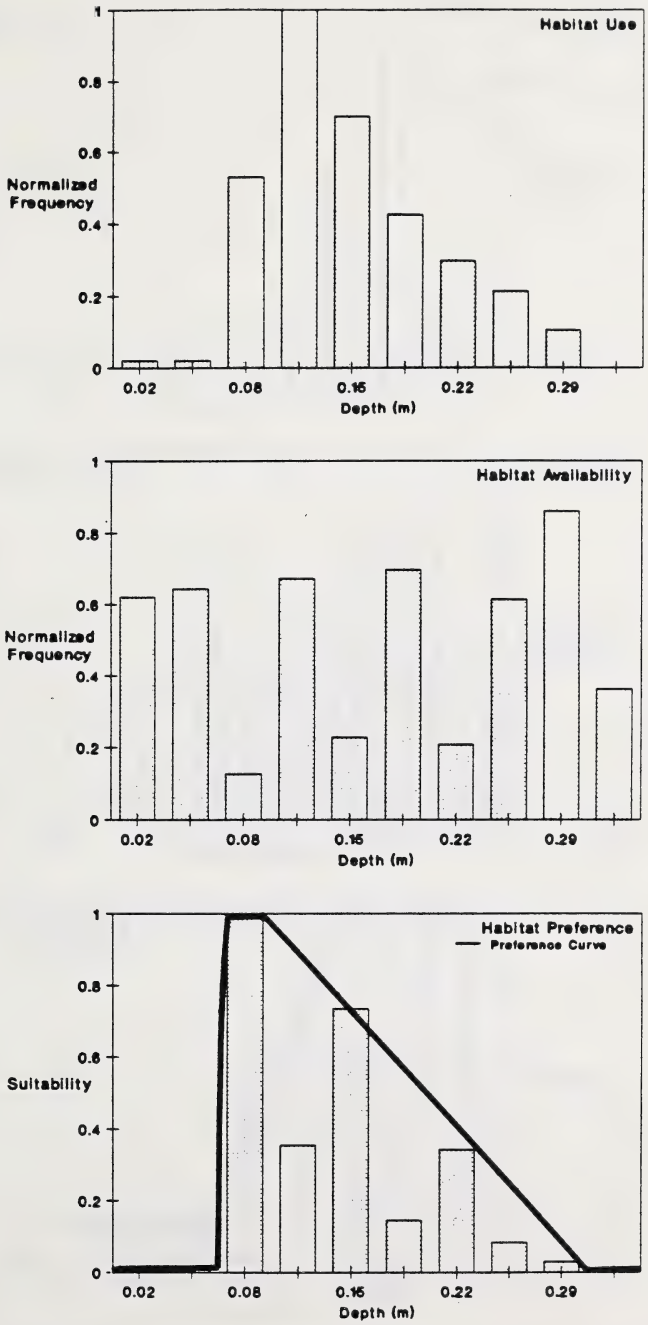



Figure IV-1. Depth use, availability and preference for brown trout fry from the Bow River.

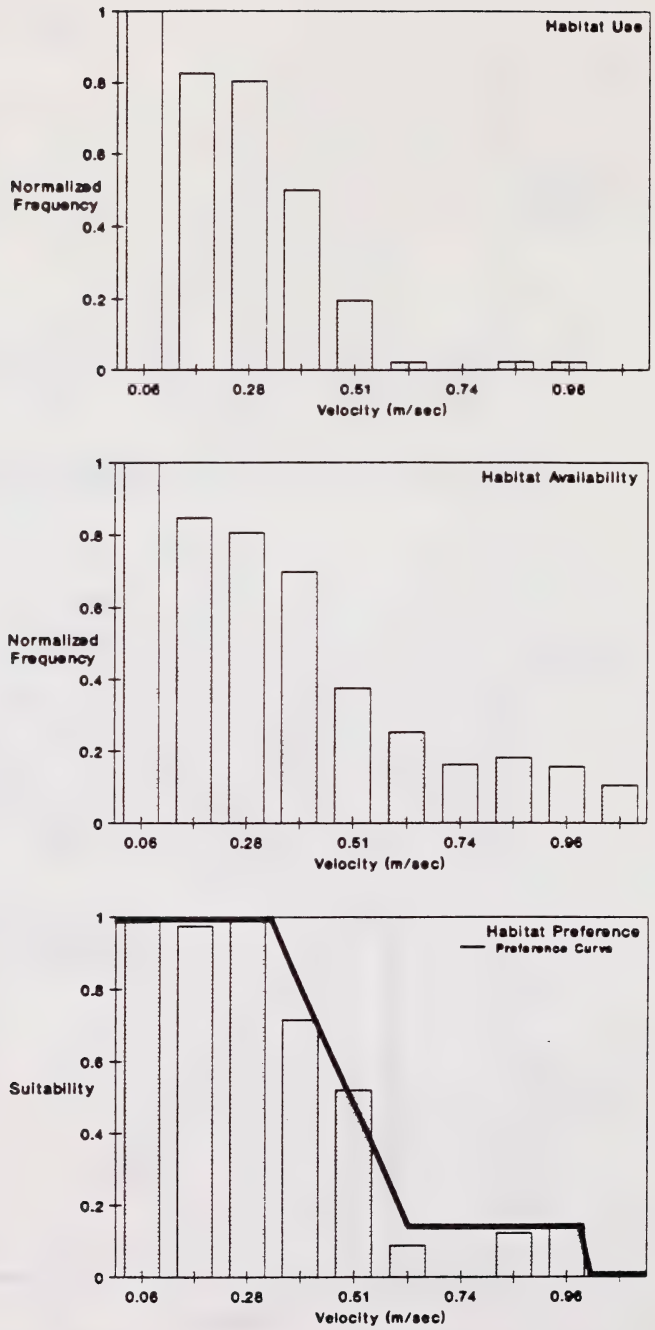



Figure IV-2. Velocity use, availability and preference for brown trout fry from the Bow River.

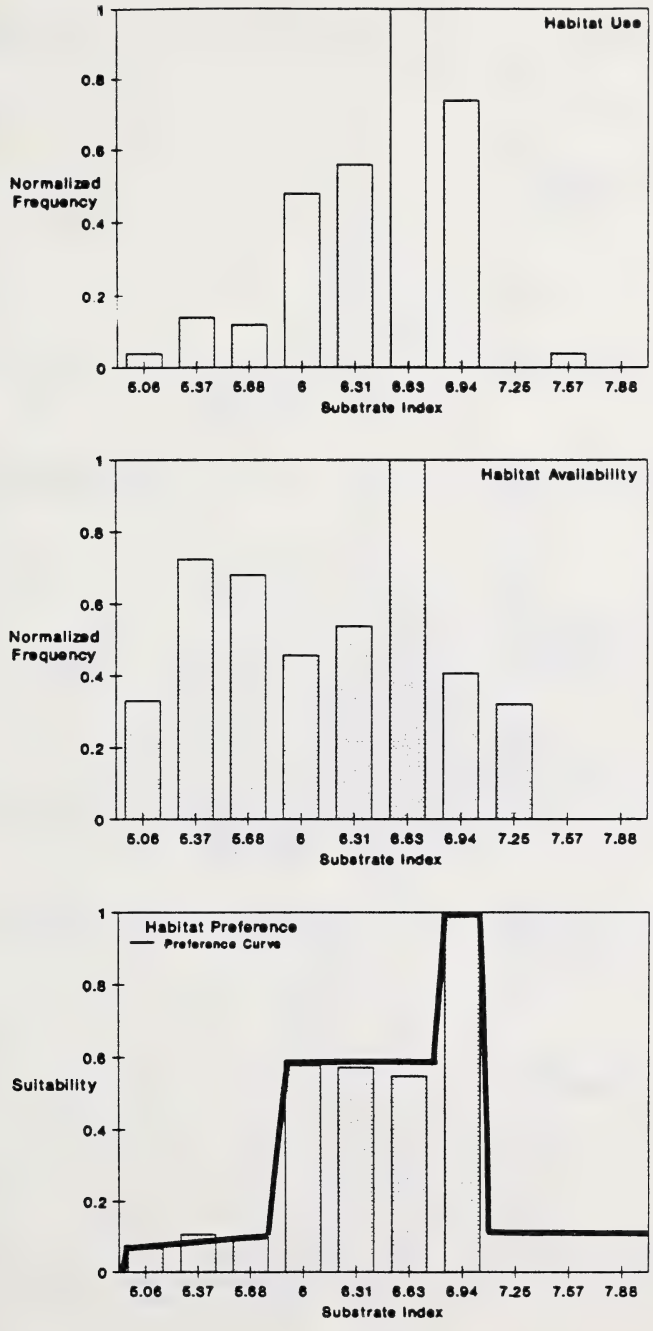



Figure IV-3. Substrate use, availability and preference for brown trout fry from the Bow River.

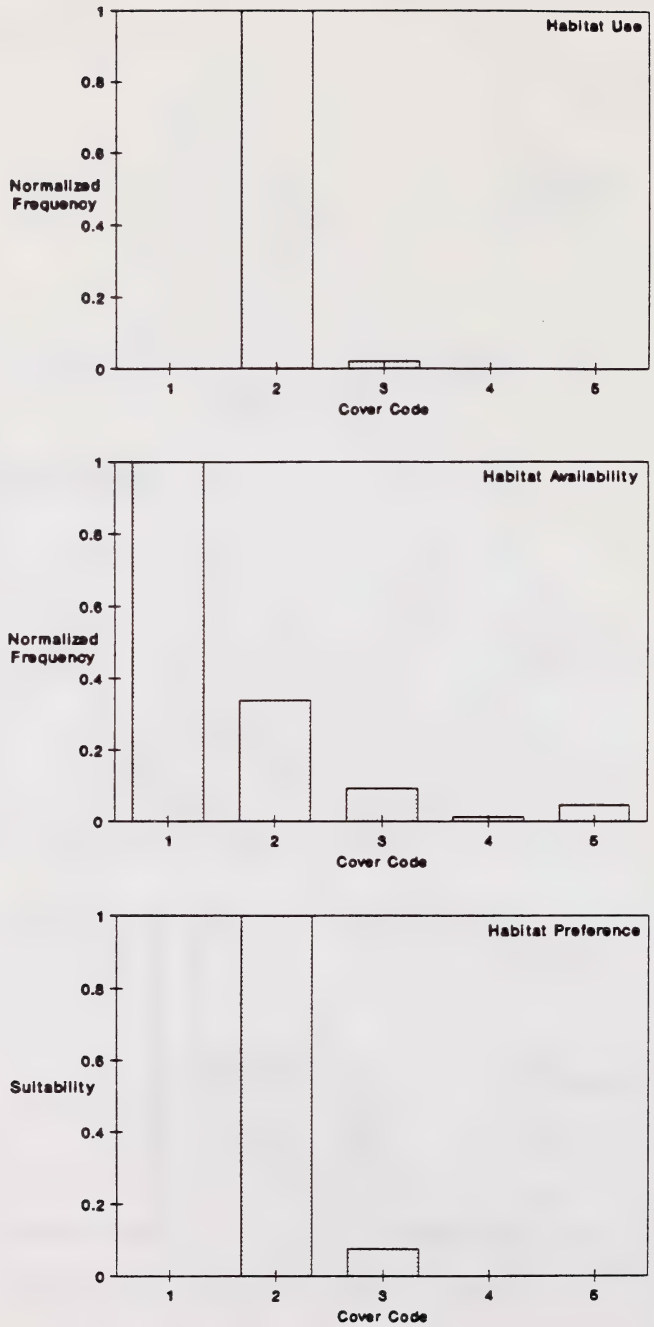



Figure IV-4. Cover use, availability and preference for brown trout fry from the Bow River.

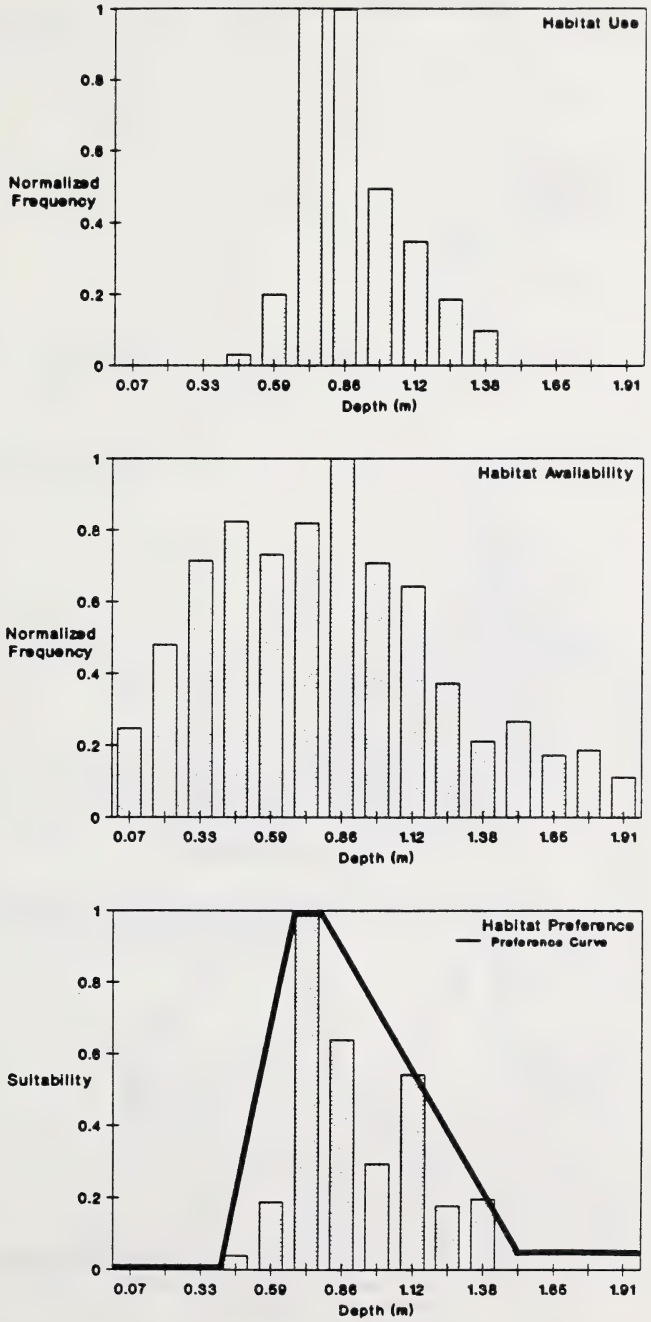



Figure IV-5. Depth use, availability and preference for brown trout juvenile from the Bow River.

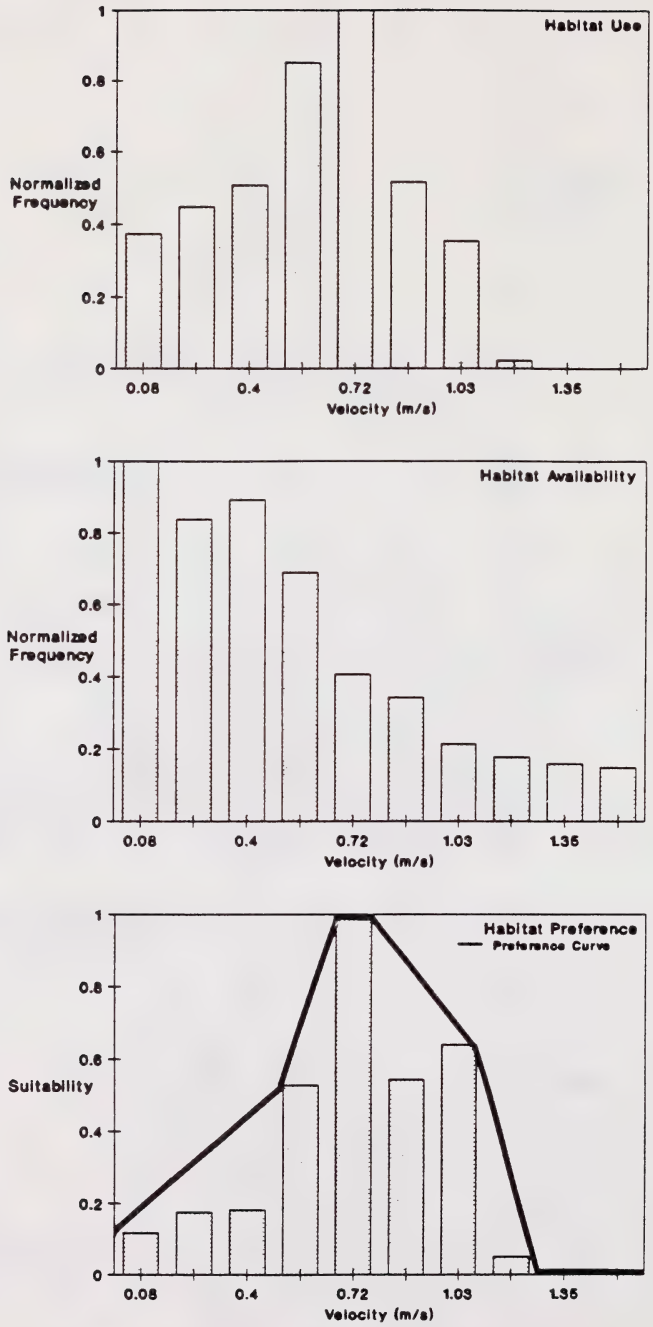



Figure IV-6. Velocity use, availability and preference for brown trout juvenile from the Bow River.

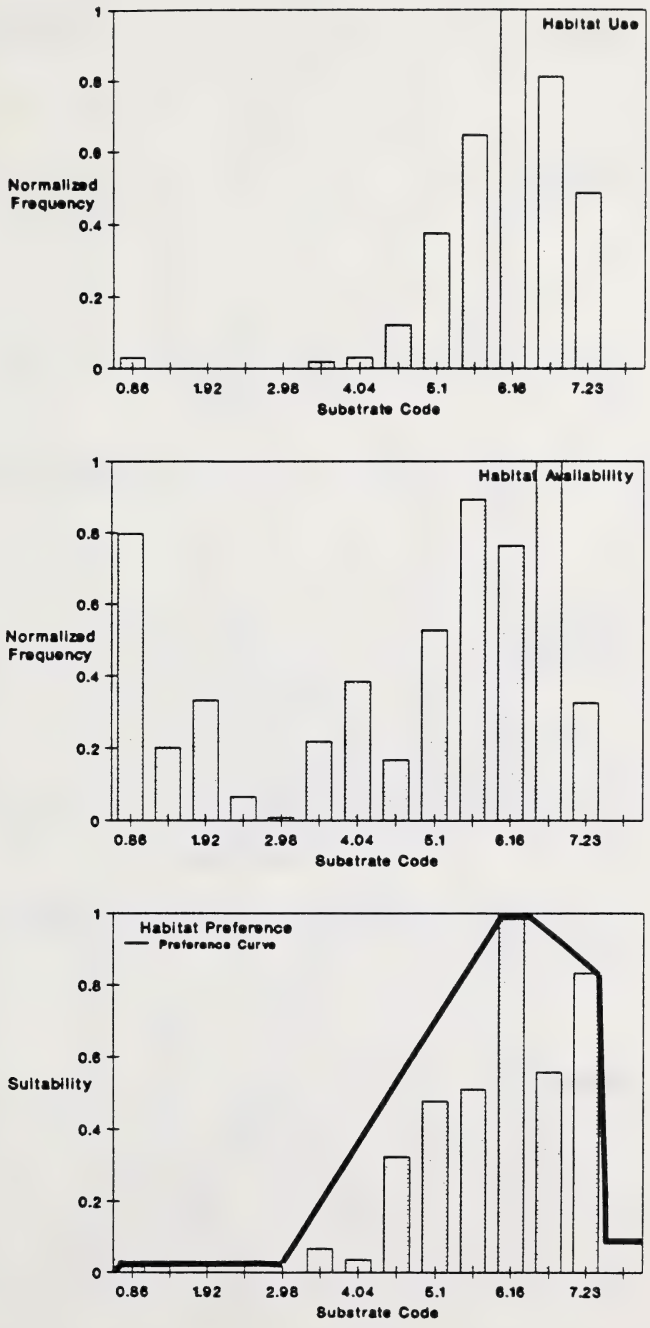



Figure IV-7. Substrate use, availability and preference for brown trout juvenile from the Bow River.

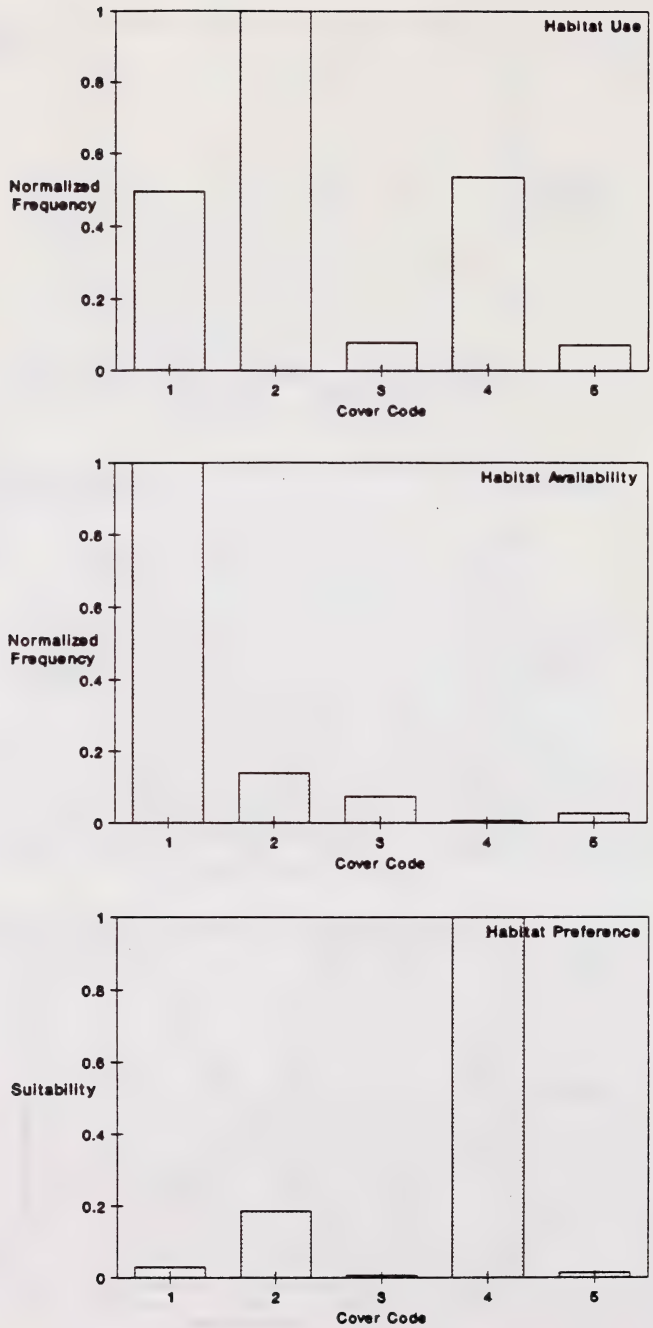



Figure IV-8. Cover use, availability and preference for brown trout juvenile from the Bow River.

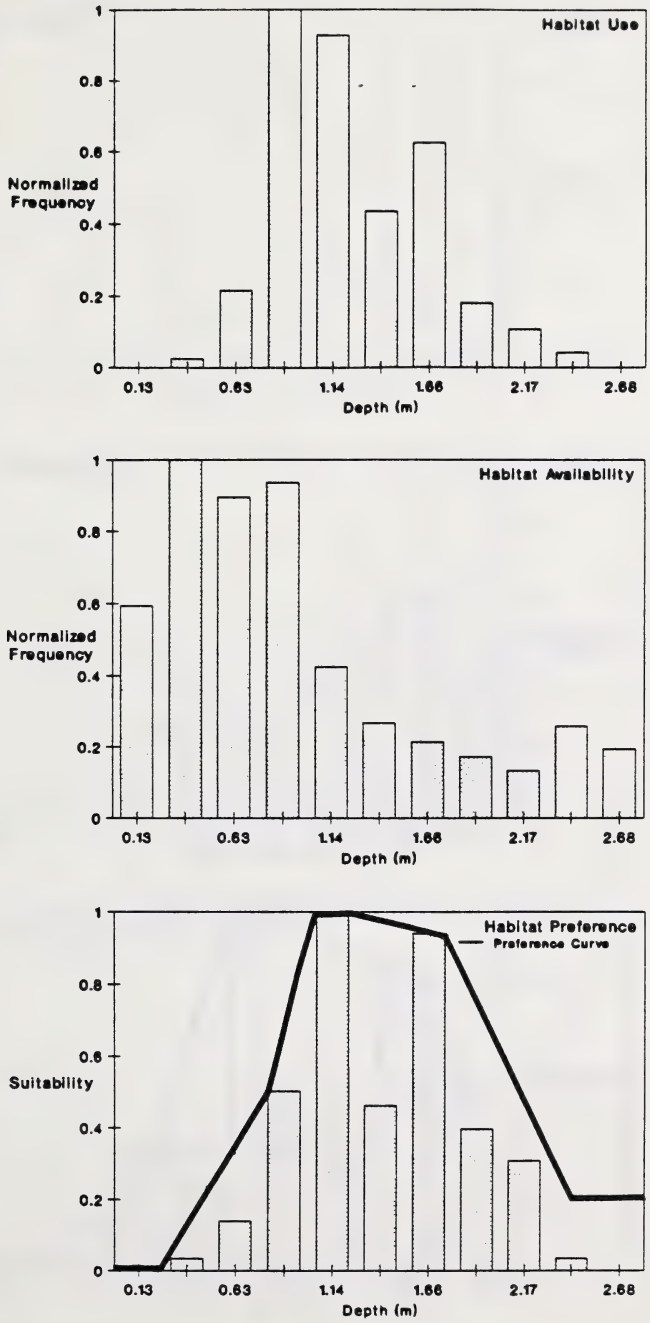



Figure IV-9. Depth use, availability and preference for brown trout adults from the Bow River.

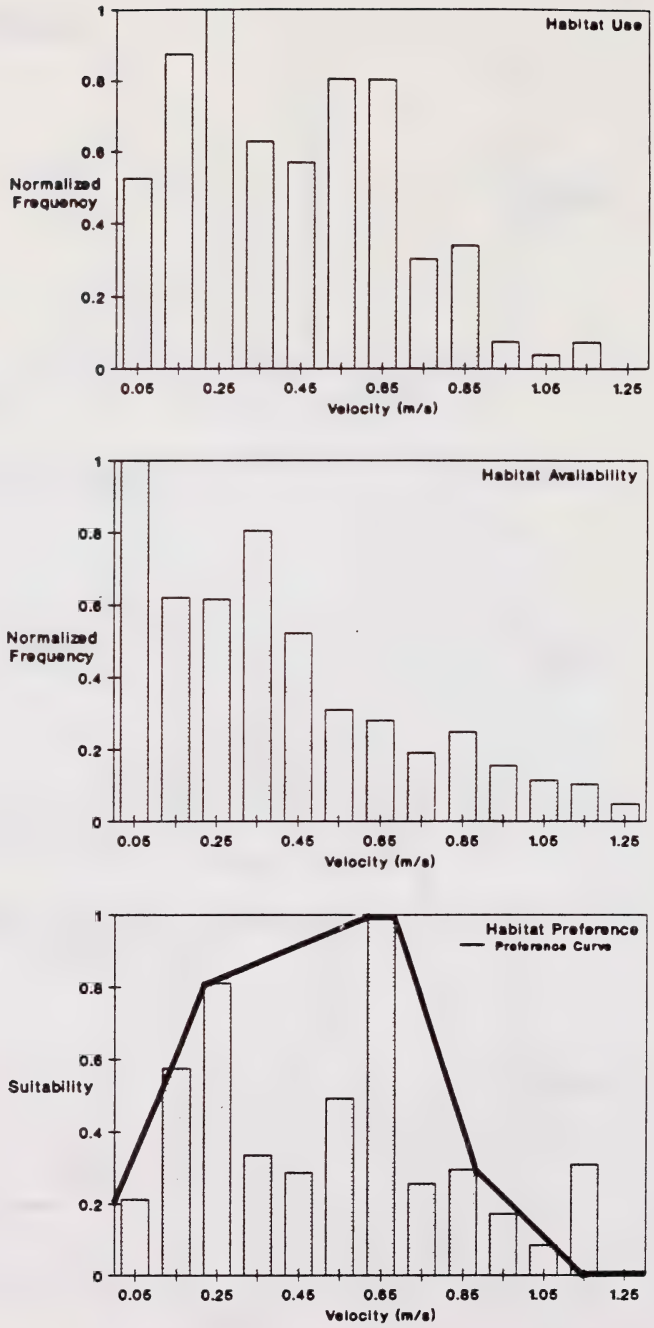



Figure IV-10. Velocity use, availability and preference for brown trout adult from the Bow River.

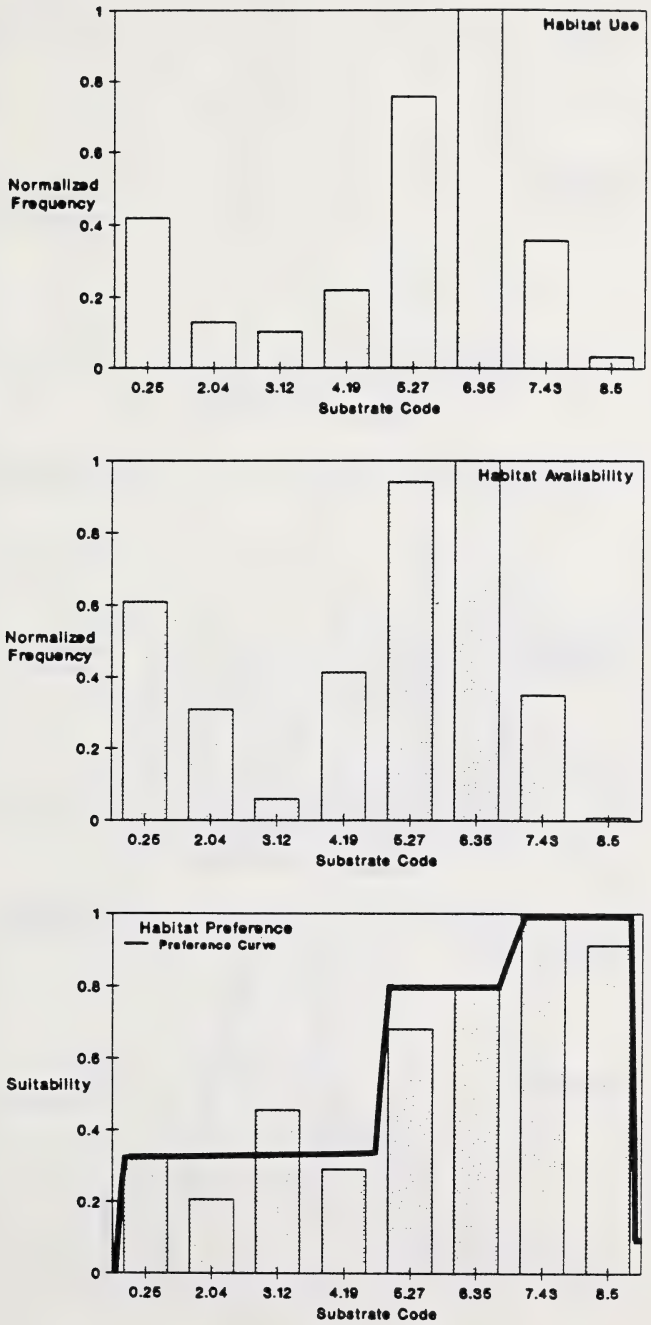



Figure IV-11. Substrate use, availability and preference for brown trout adult from the Bow River.

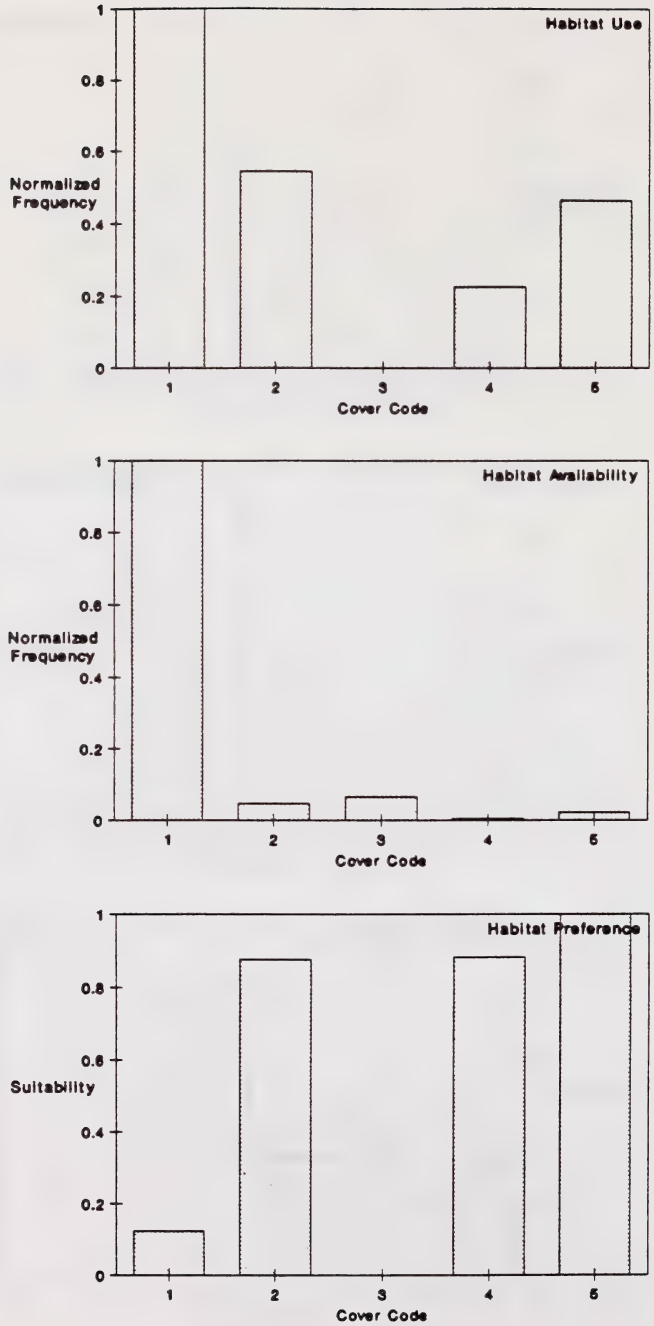



Figure IV-12. Cover use, availability and preference for brown trout adult from the Bow River.

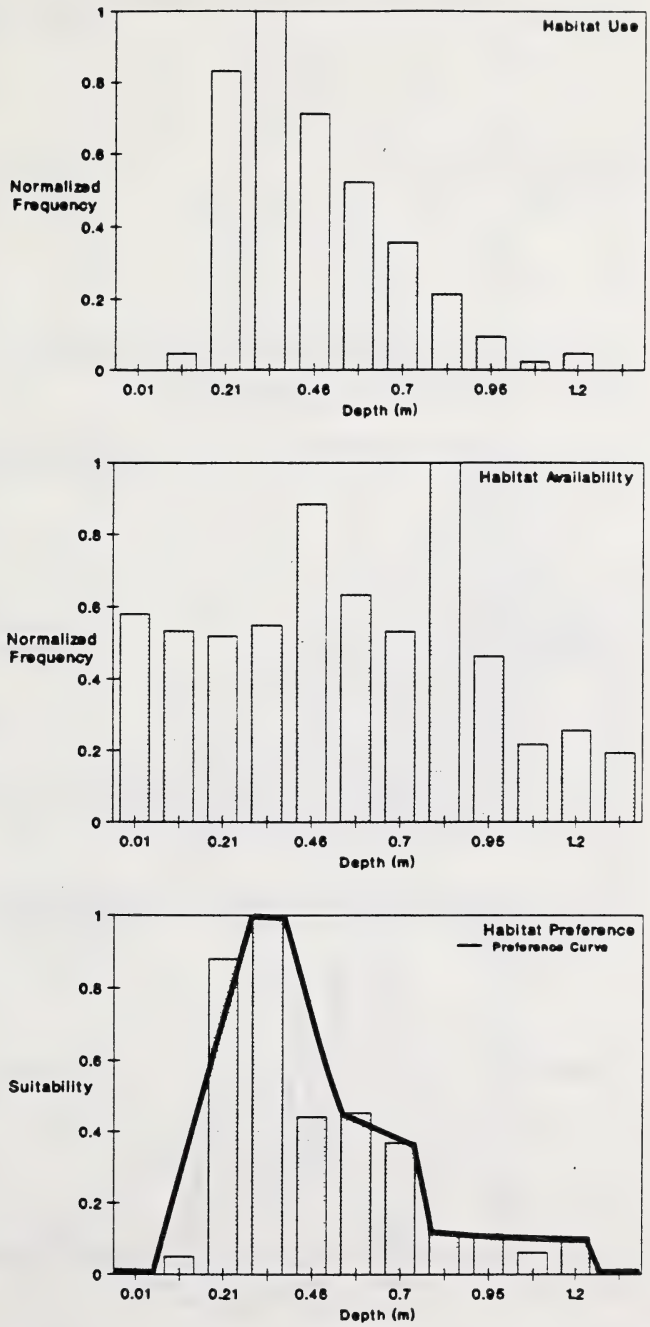



Figure IV-13. Depth use, availability and preference for brown trout spawning from the Bow River.

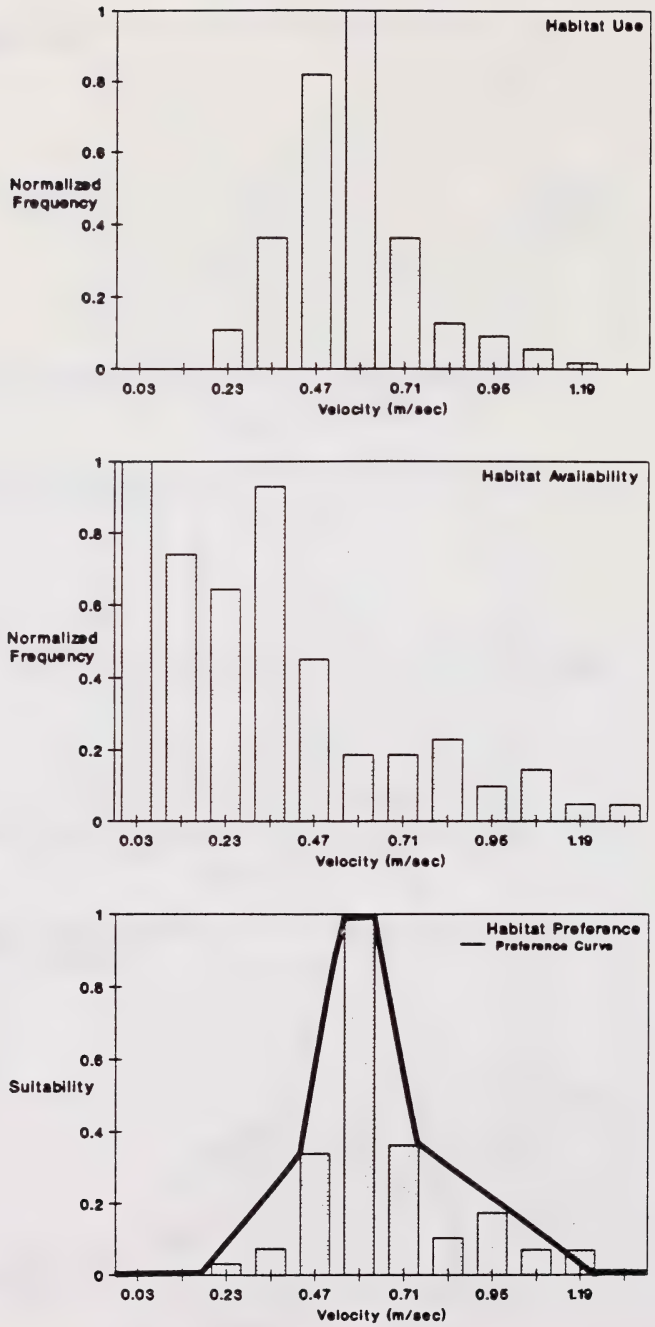



Figure IV-14. Velocity use, availability and preference for brown trout spawning from the Bow River.

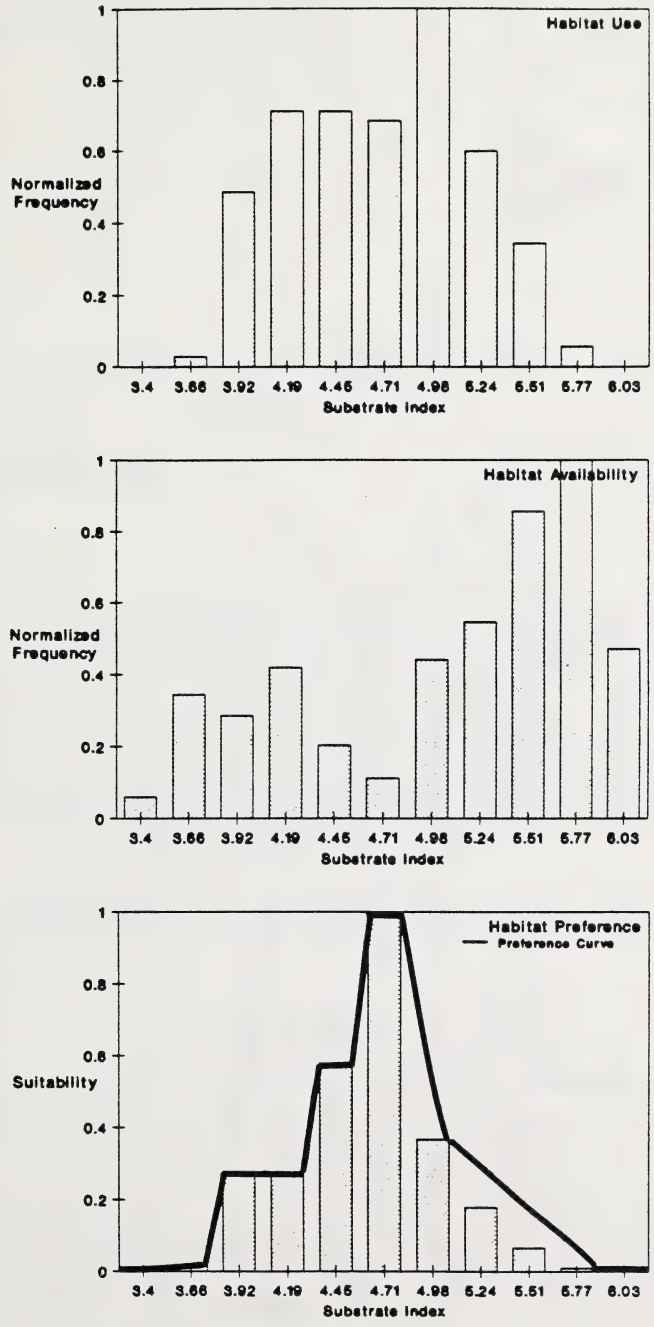



Figure IV-15. Substrate use, availability and preference for brown trout spawning from the Bow River.

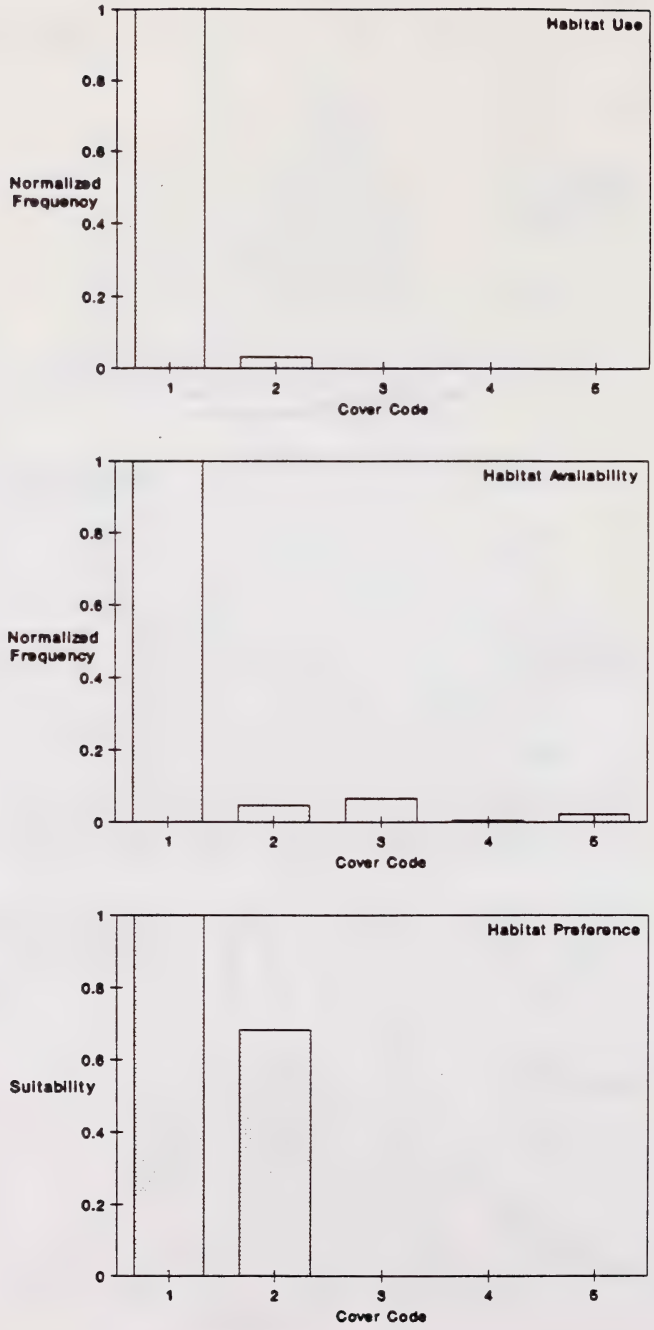



Figure IV-16. Cover use, availability and preference for brown trout spawning from the Bow River.

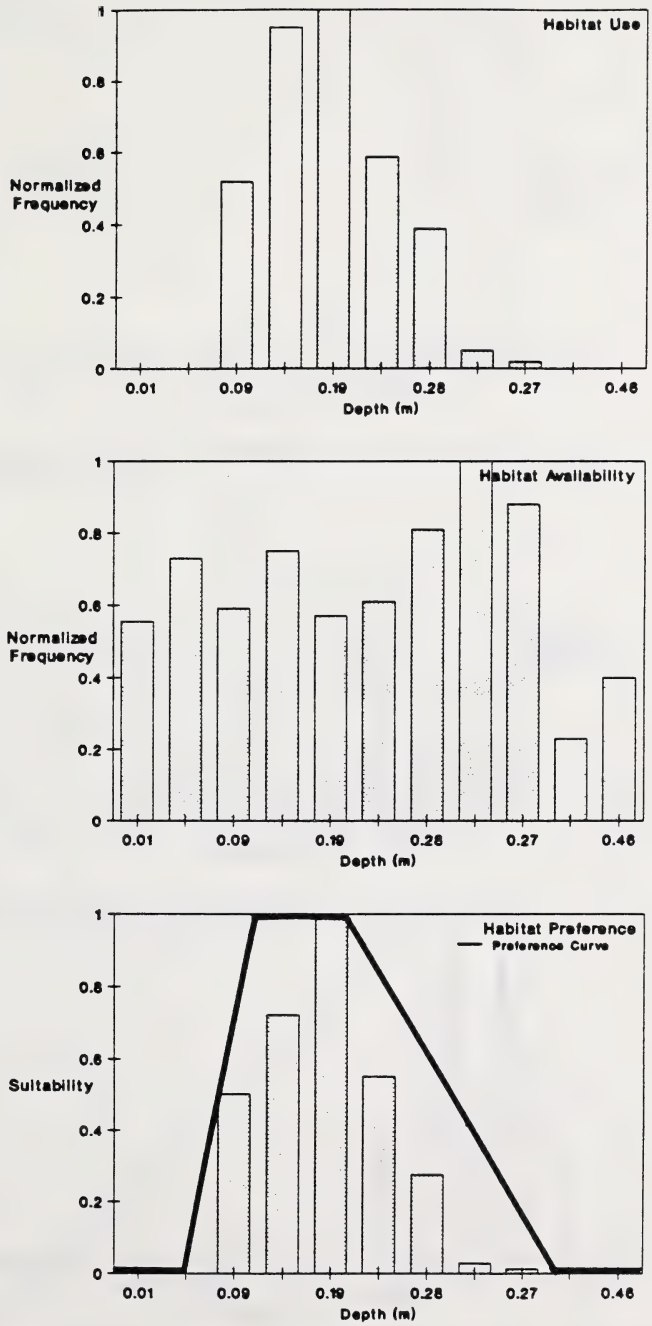



Figure IV-17. Depth use, availability and preference for rainbow trout fry from the Crowsnest River.

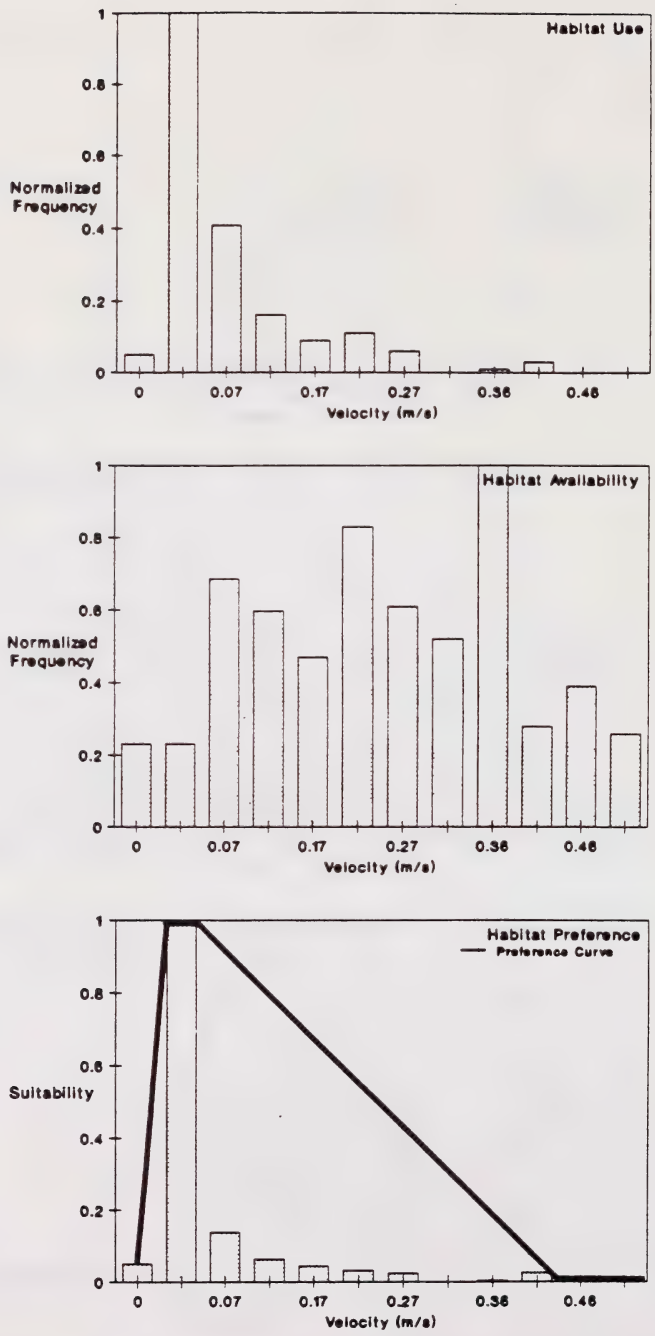



Figure IV-18. Velocity use, availability and preference for rainbow trout fry from the Crowsnest River.

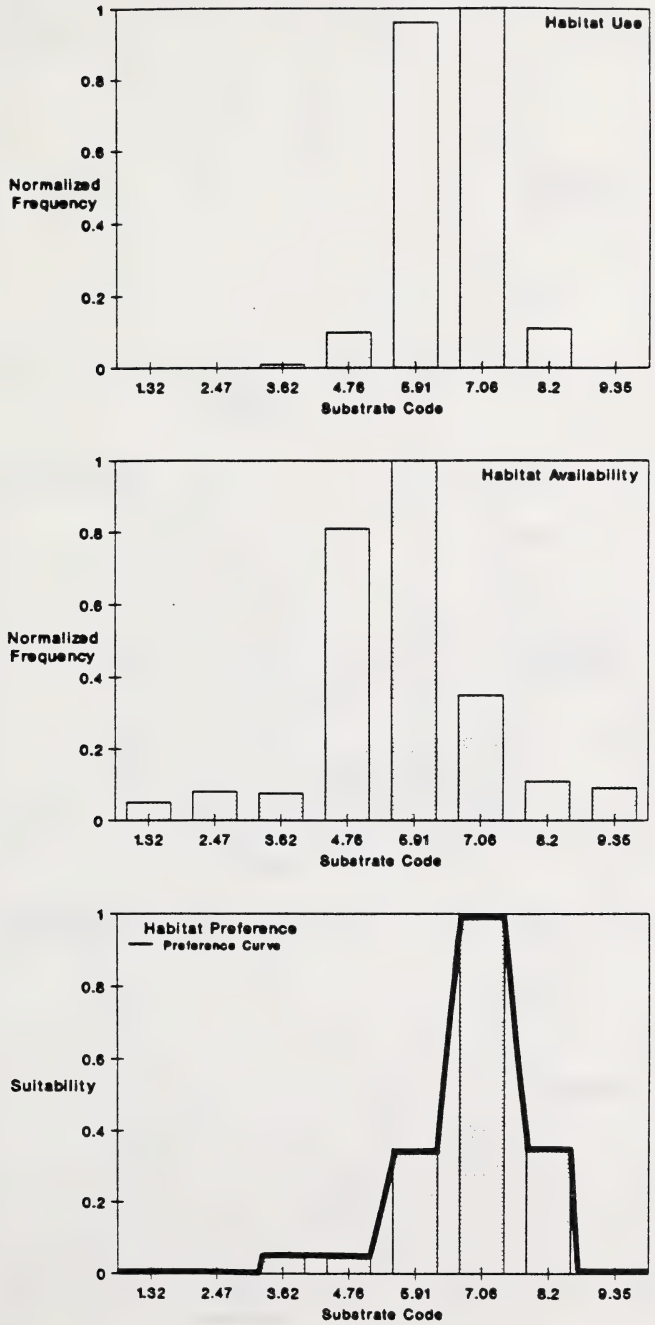



Figure IV-19. Substrate use, availability and preference for rainbow trout fry from the Crowsnest River.

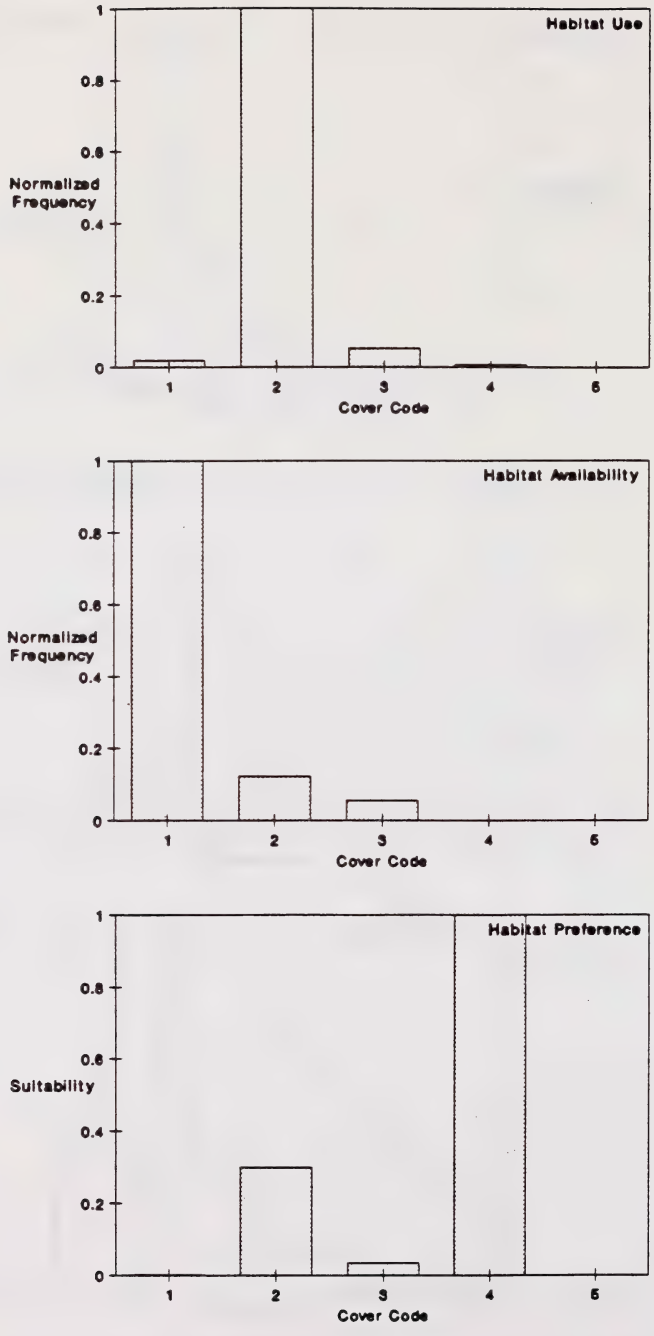



Figure IV-20. Cover use, availability and preference for rainbow trout fry from the Crowsnest River.

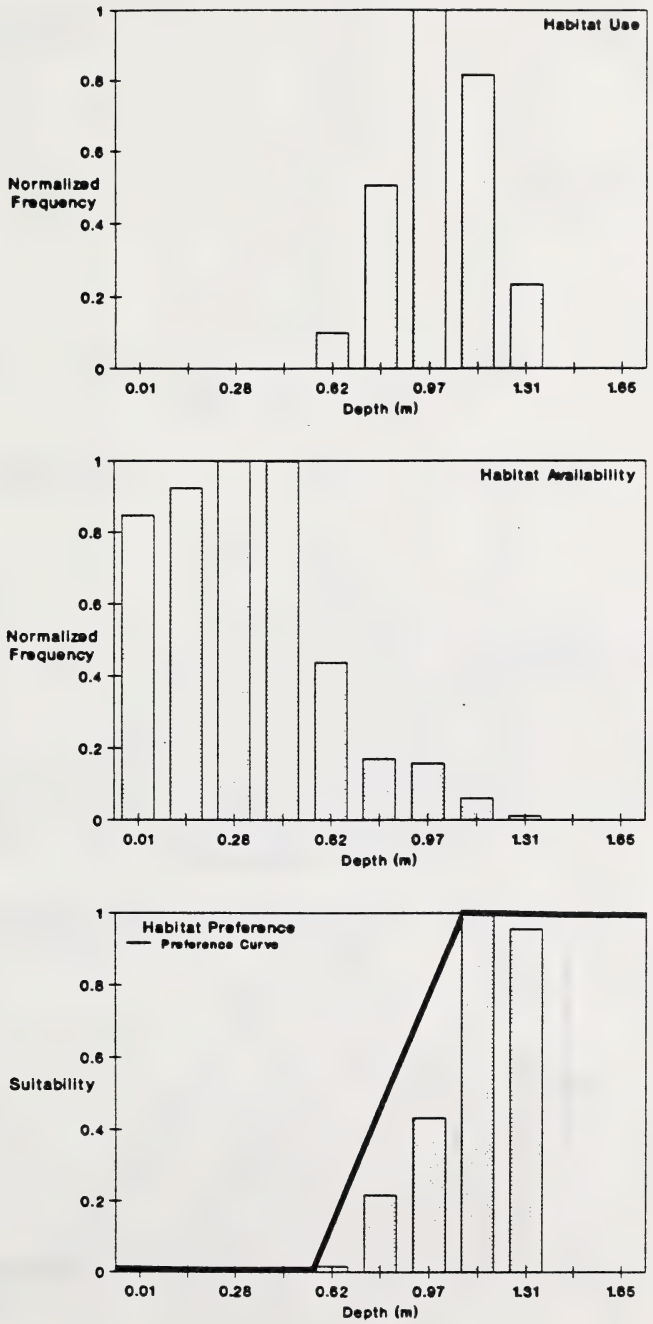



Figure IV-21. Depth use, availability and preference for rainbow trout adults from the Crowsnest River.

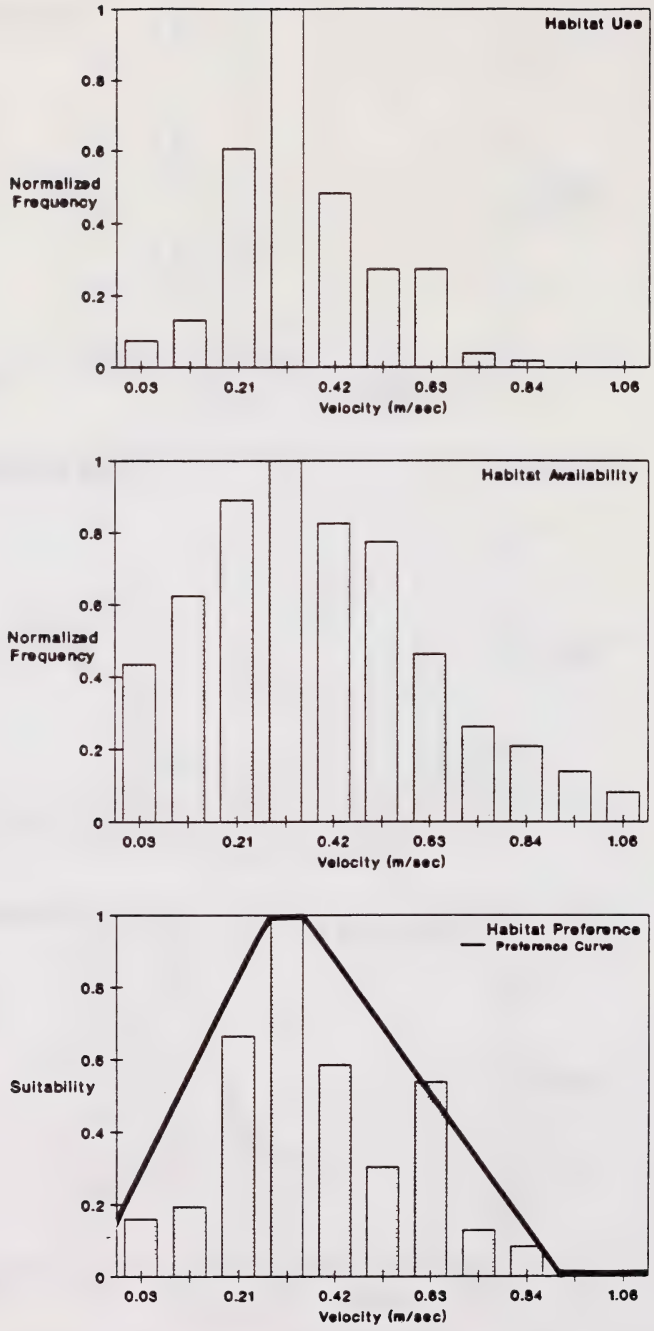



Figure IV-22. Velocity use, availability and preference for rainbow trout adults from the Crowsnest River.

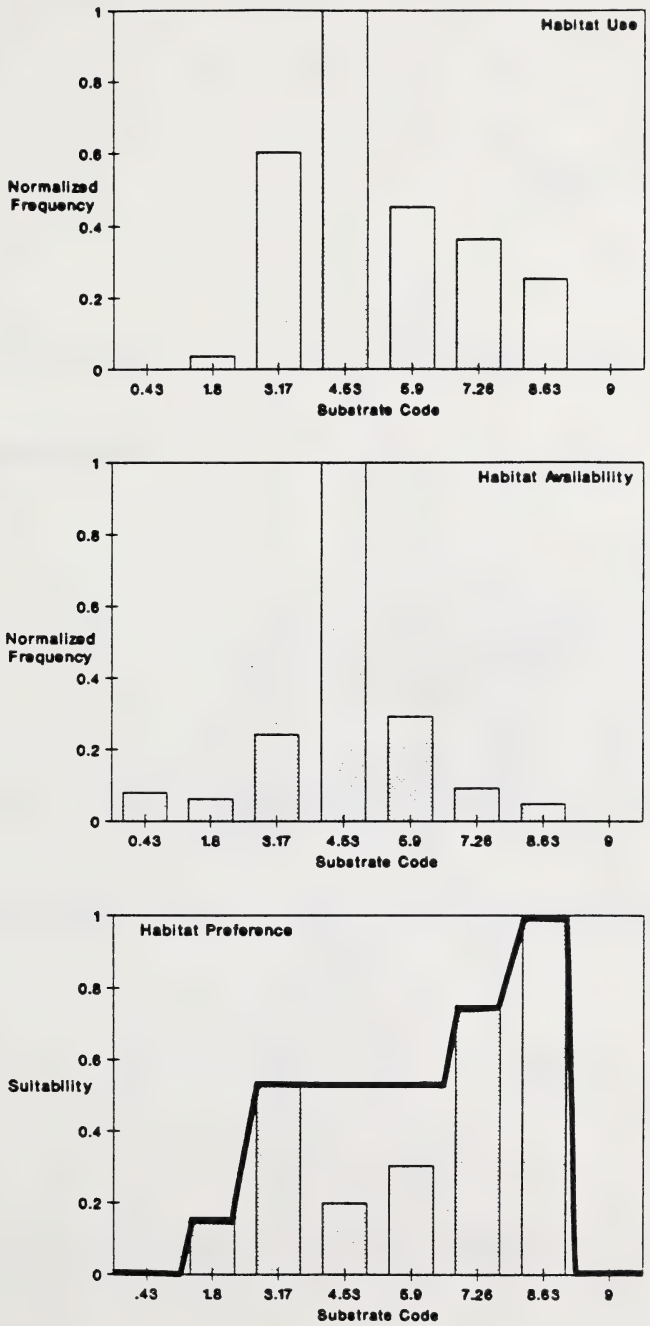



Figure IV-23. Substrate use, availability and preference for rainbow trout adults from the Crowsnest River.

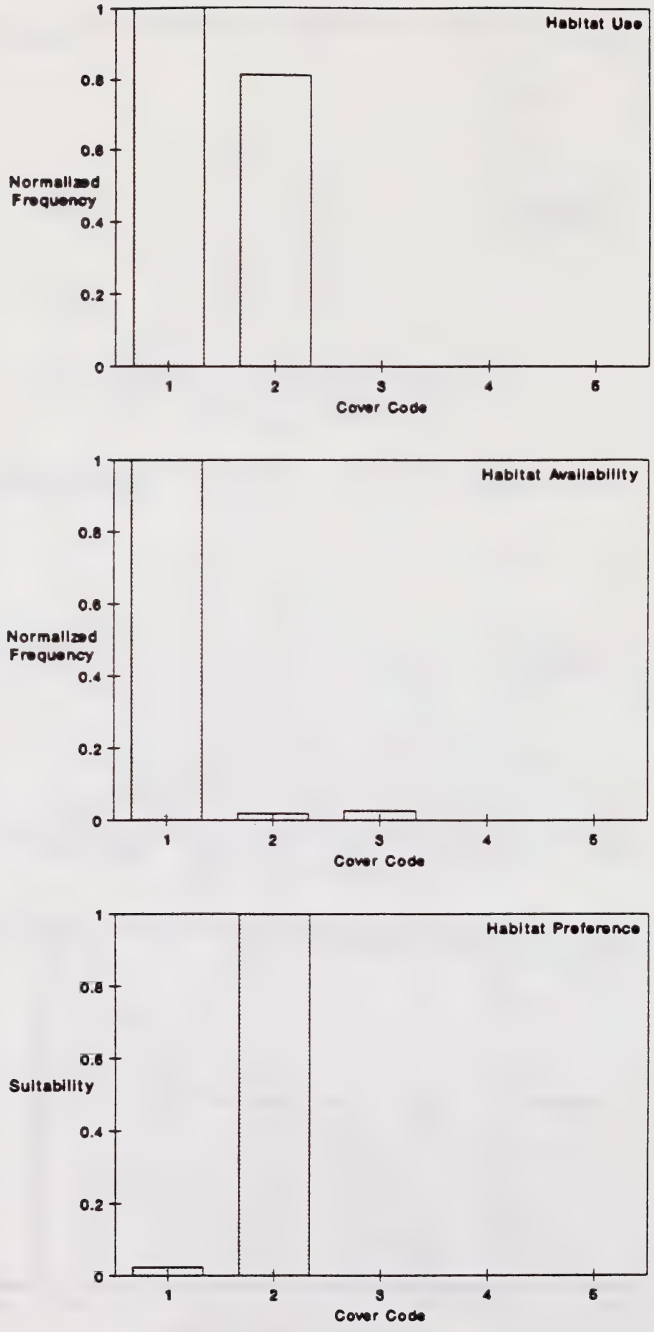



Figure IV-24. Cover use, availability and preference for rainbow trout adults from the Crowsnest River.

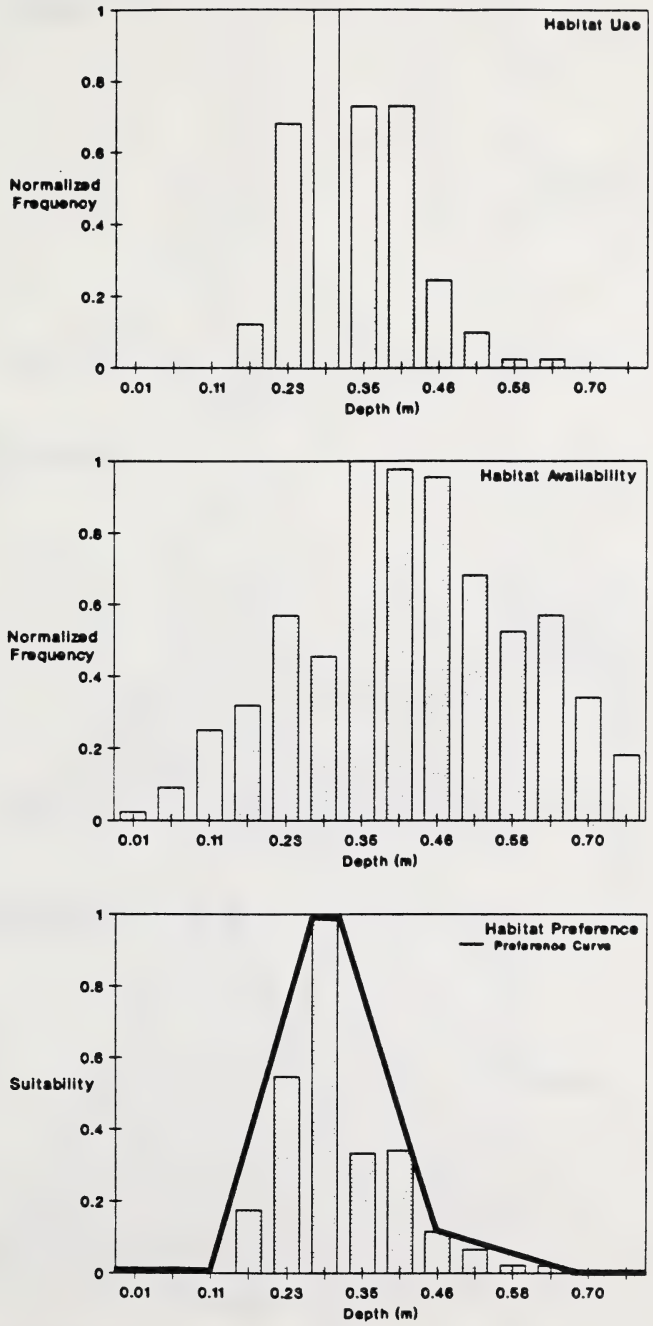



Figure IV-25. Depth use, availability and preference for rainbow trout spawning from the Crowsnest River.

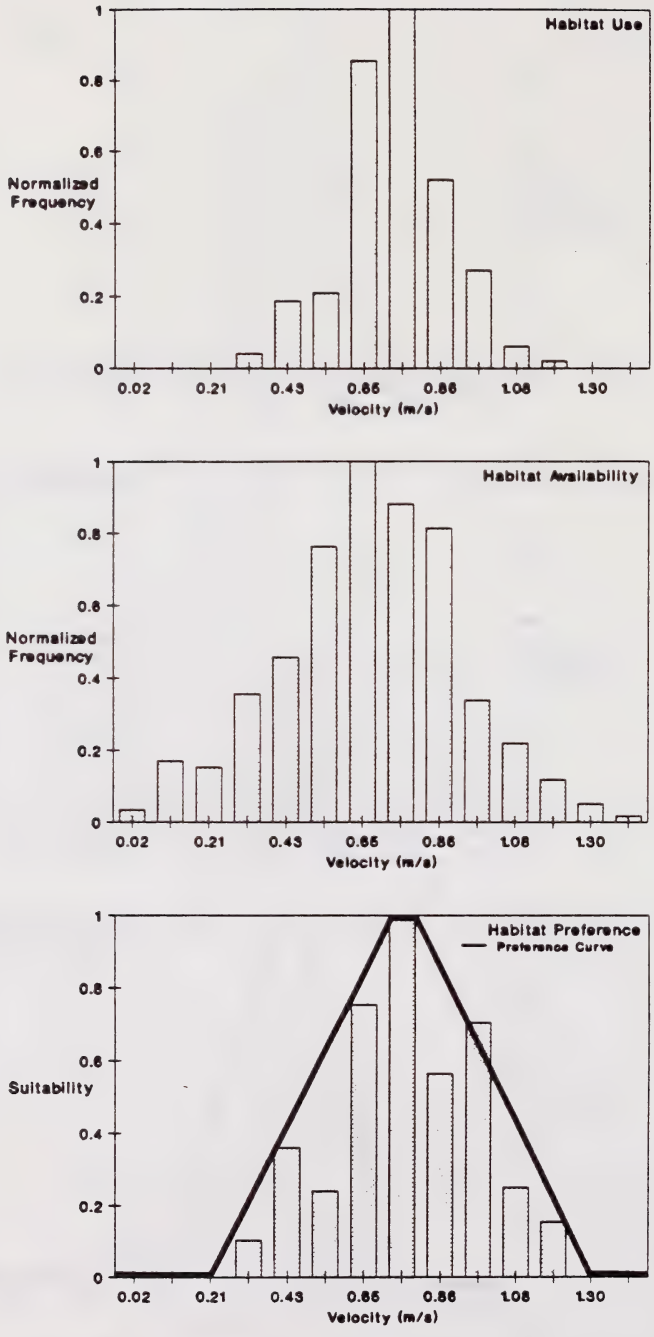



Figure IV-26. Velocity use, availability and preference for rainbow trout spawning from the Crowsnest River.

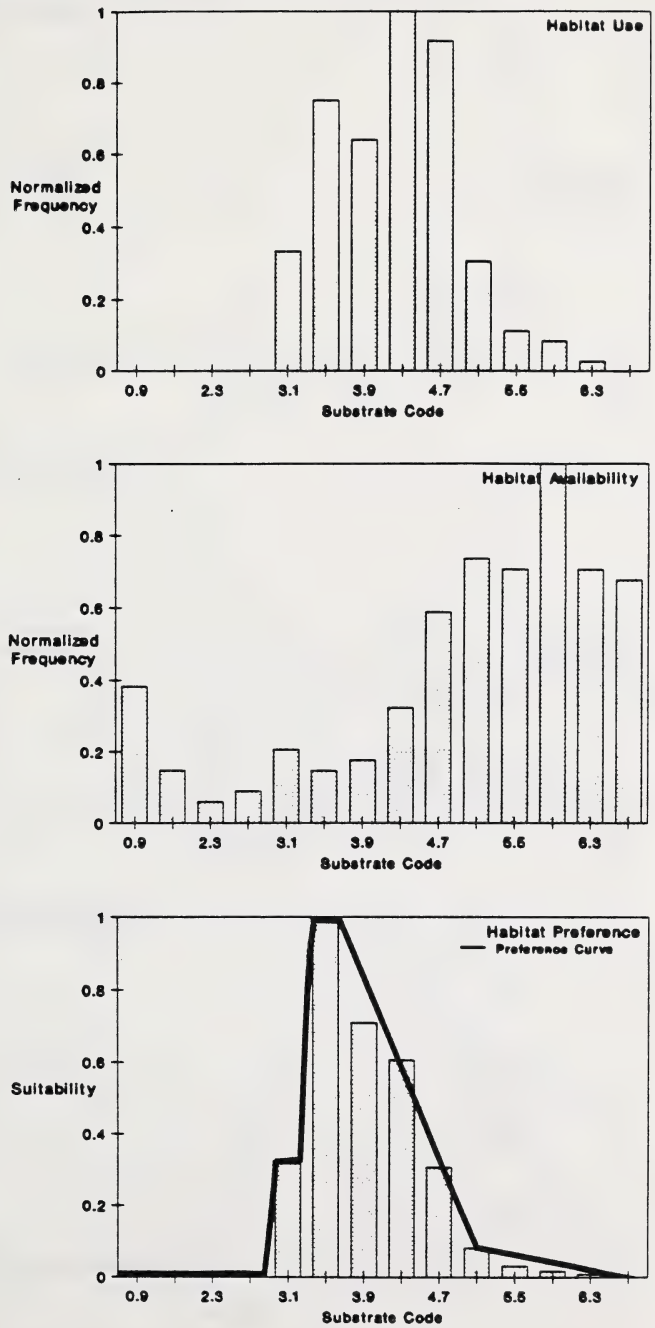



Figure IV-27. Substrate use, availability and preference for rainbow trout spawning from the Crowsnest River.

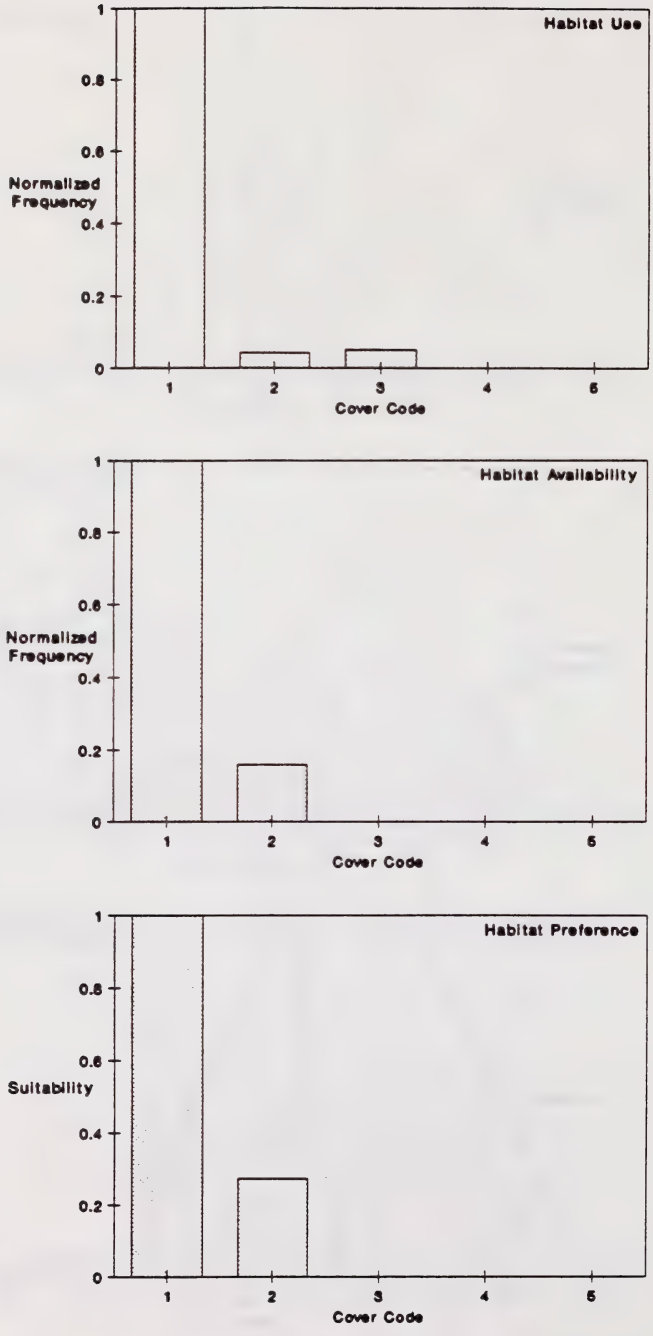



Figure IV-28. Cover use, availability and preference for rainbow trout spawning from the Crowsnest River.

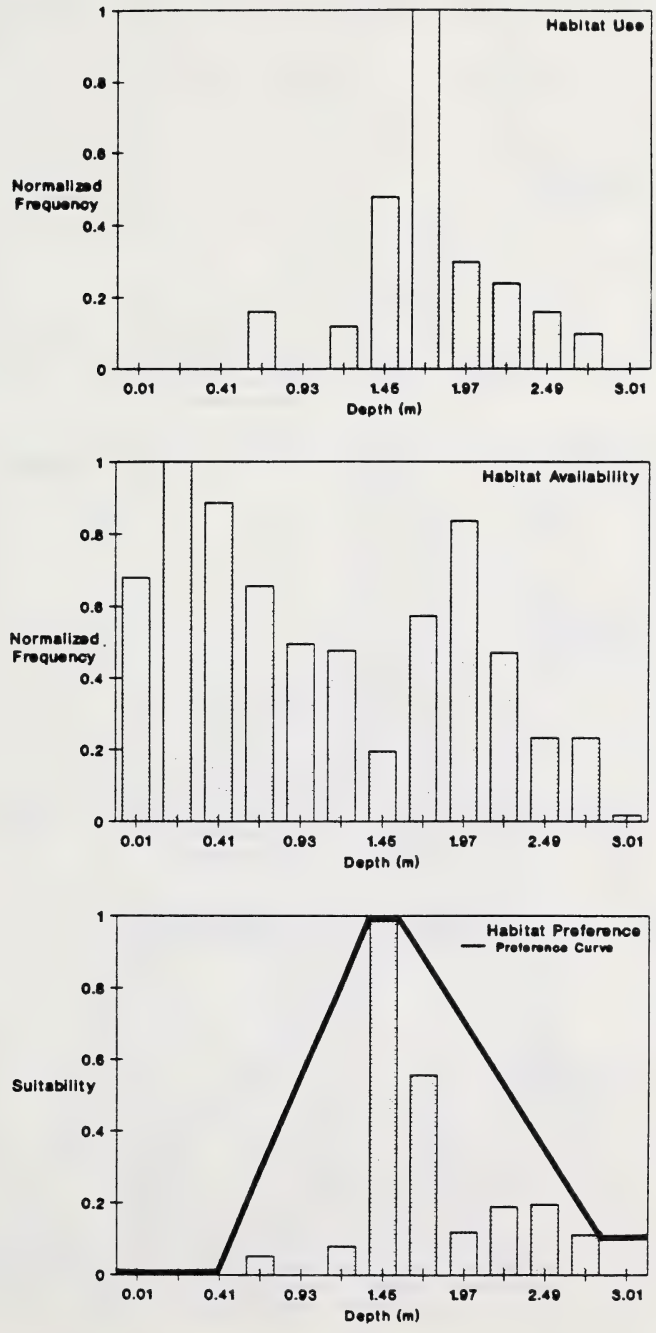



Figure IV-29. Depth use, availability and preference for sauger juvenile (day) from the Oldman River.

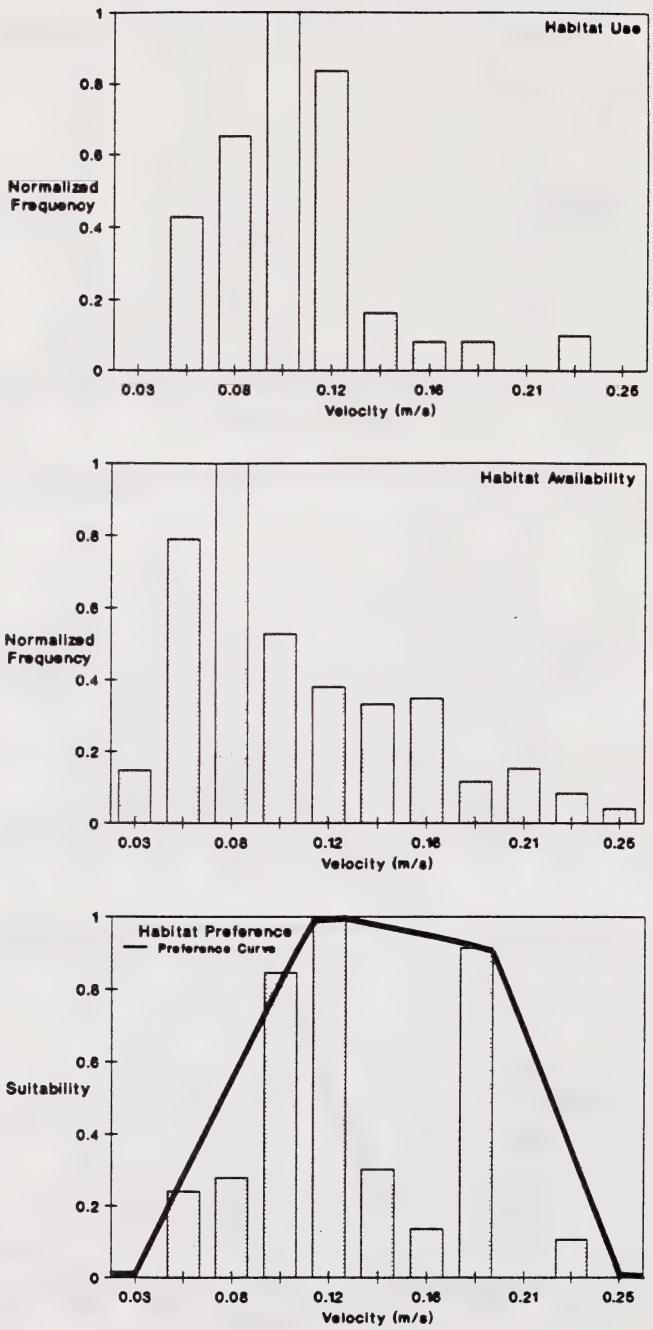



Figure IV-30. Velocity use, availability and preference for sauger juvenile (day) from the Oldman River.

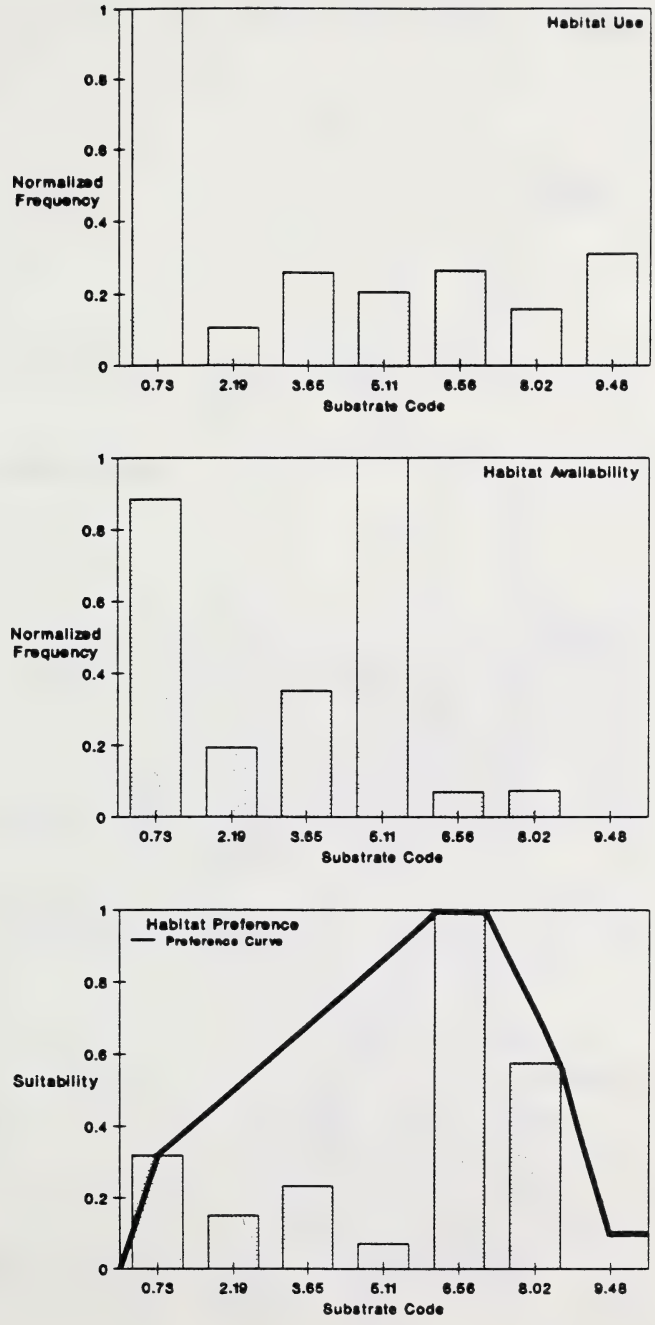



Figure IV-31. Substrate use, availability and preference for sauger juvenile (day) from the Oldman River.

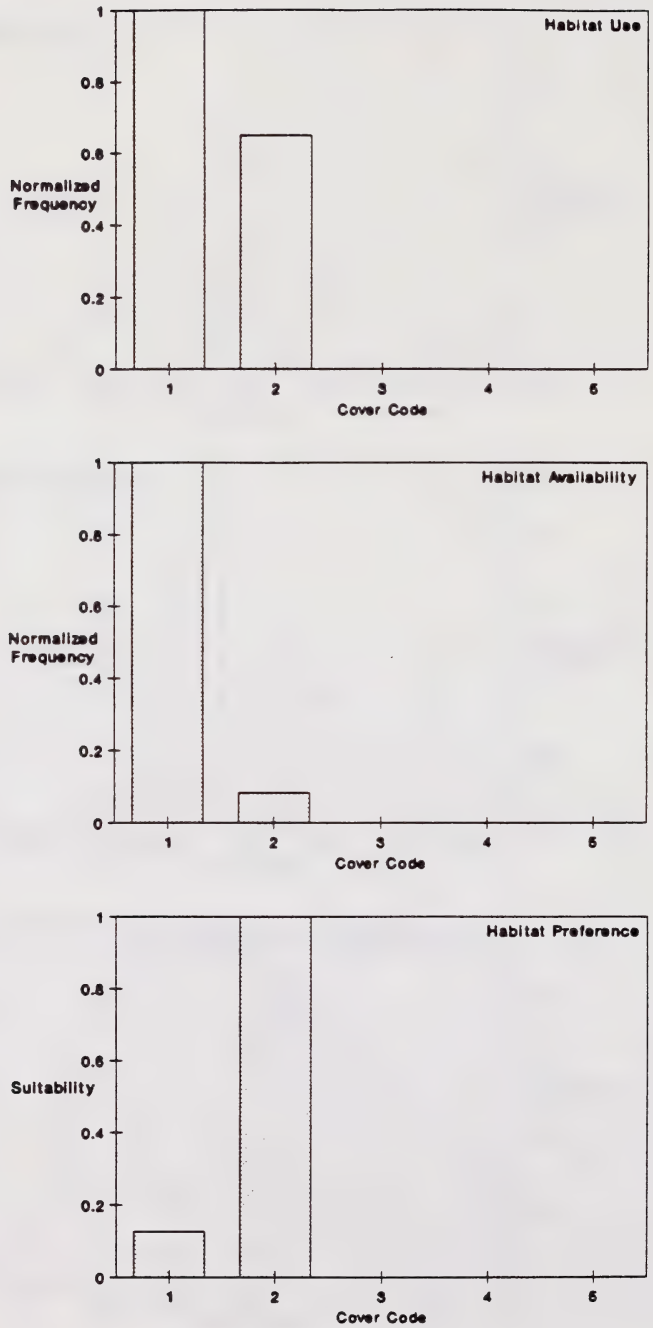



Figure IV-32. Cover use, availability and preference for sauger juvenile (day) from the Oldman River.

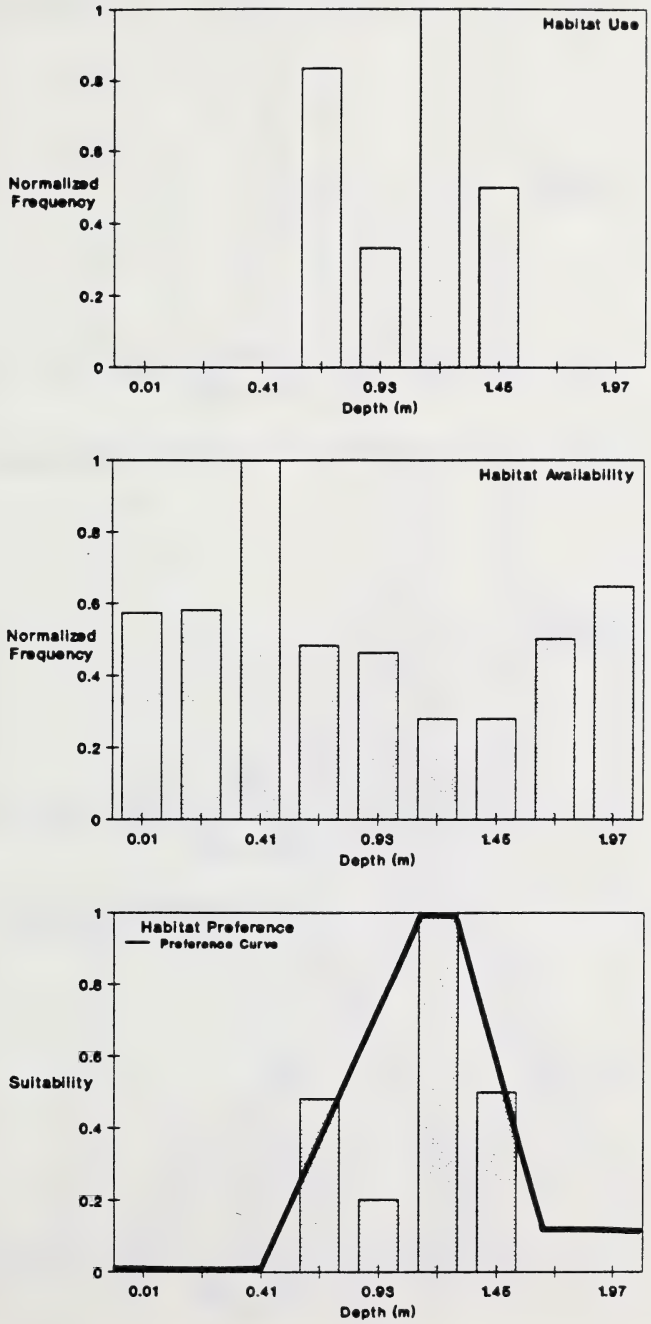



Figure IV-33. Depth use, availability and preference for sauger juvenile (night) from the Oldman River.

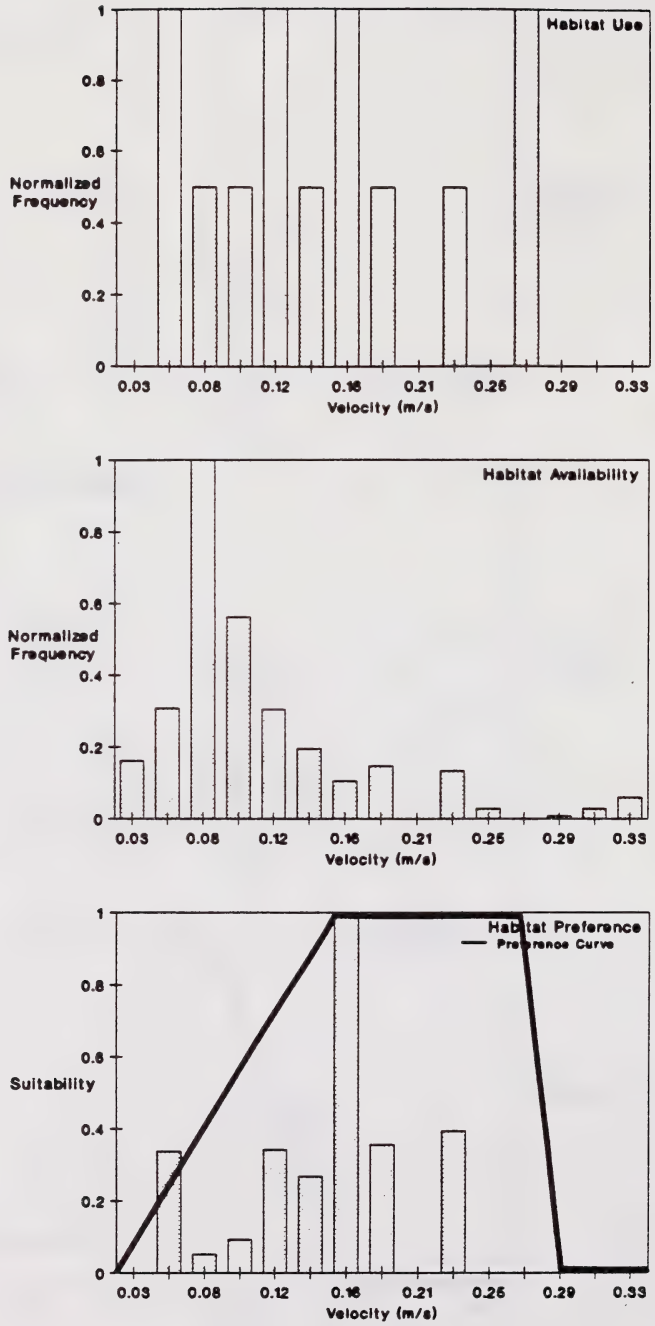



Figure IV-34. Velocity use, availability and preference for sauger juvenile (night) from the Oldman River.

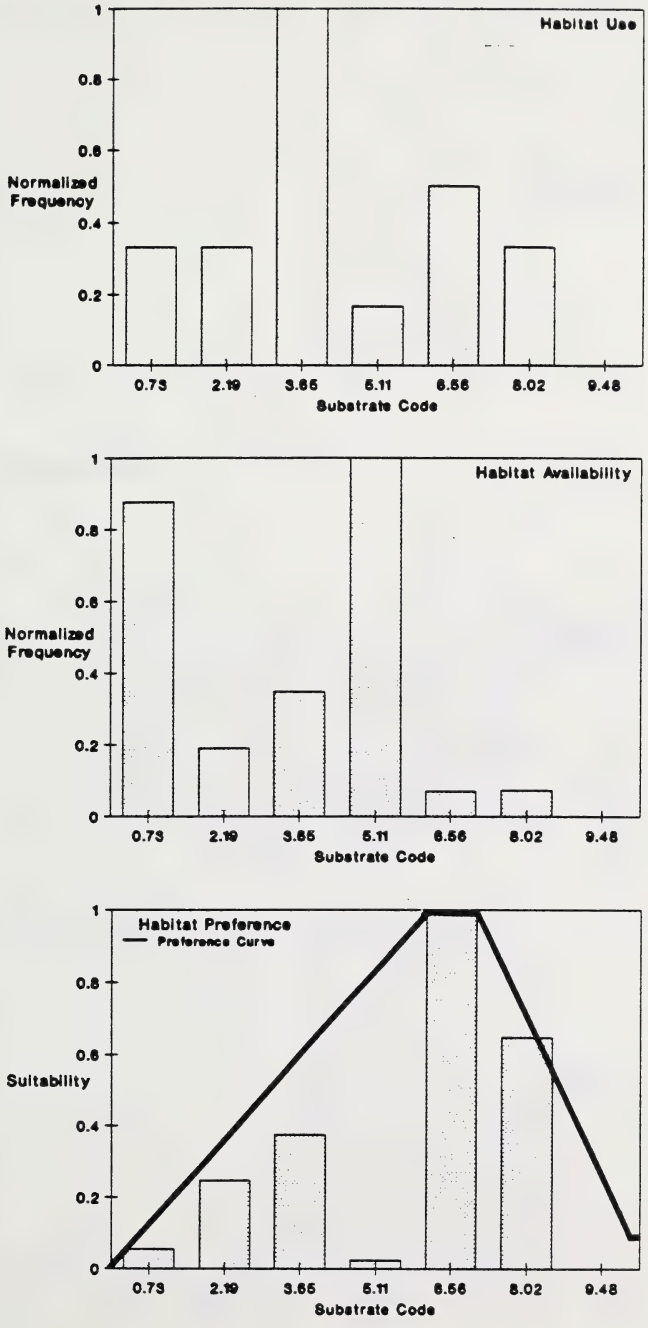



Figure IV-35. Substrate use, availability and preference for sauger juvenile (night) from the Oldman River.

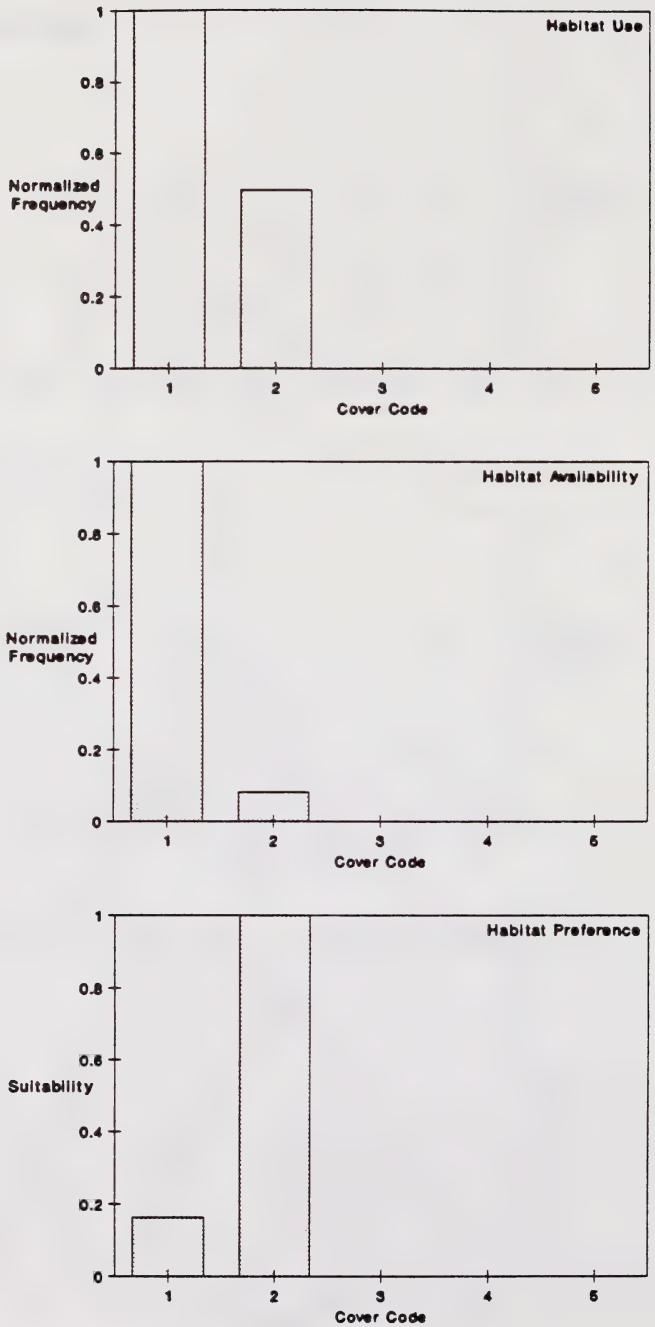



Figure IV-36. Cover use, availability and preference for sauger juvenile (night) from the Oldman River.

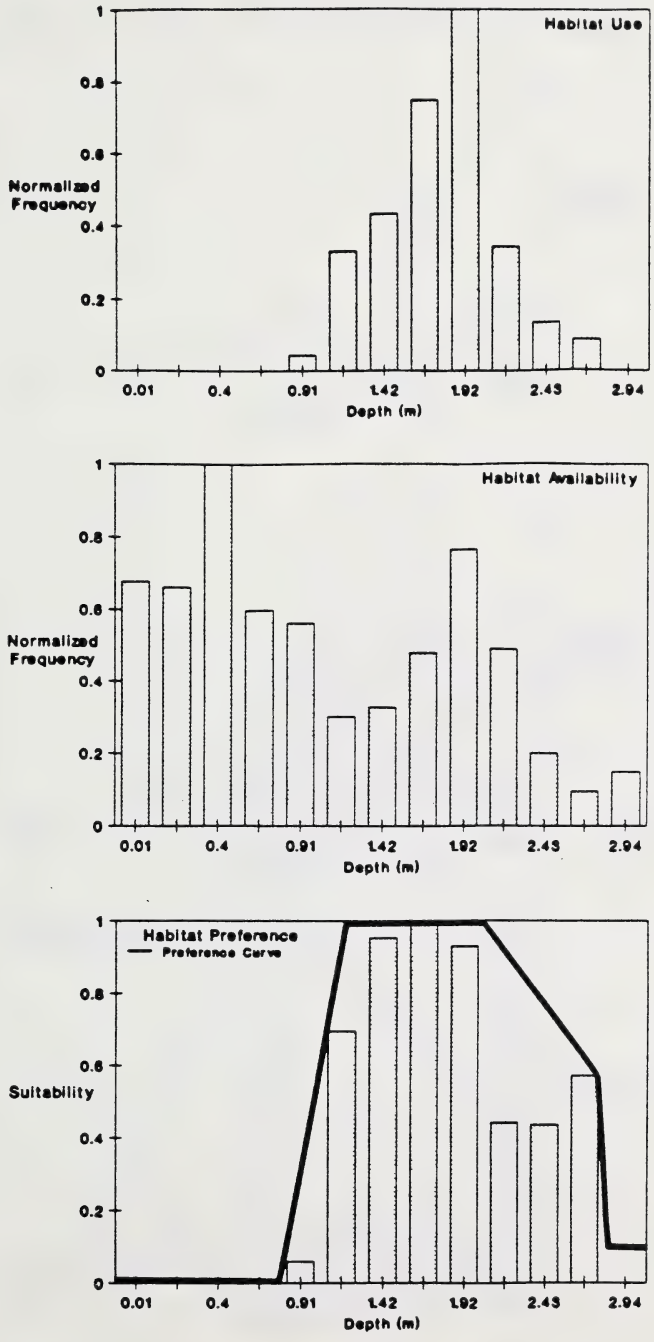



Figure IV-37. Depth use, availability and preference for sauger adult (day) from the Oldman River.

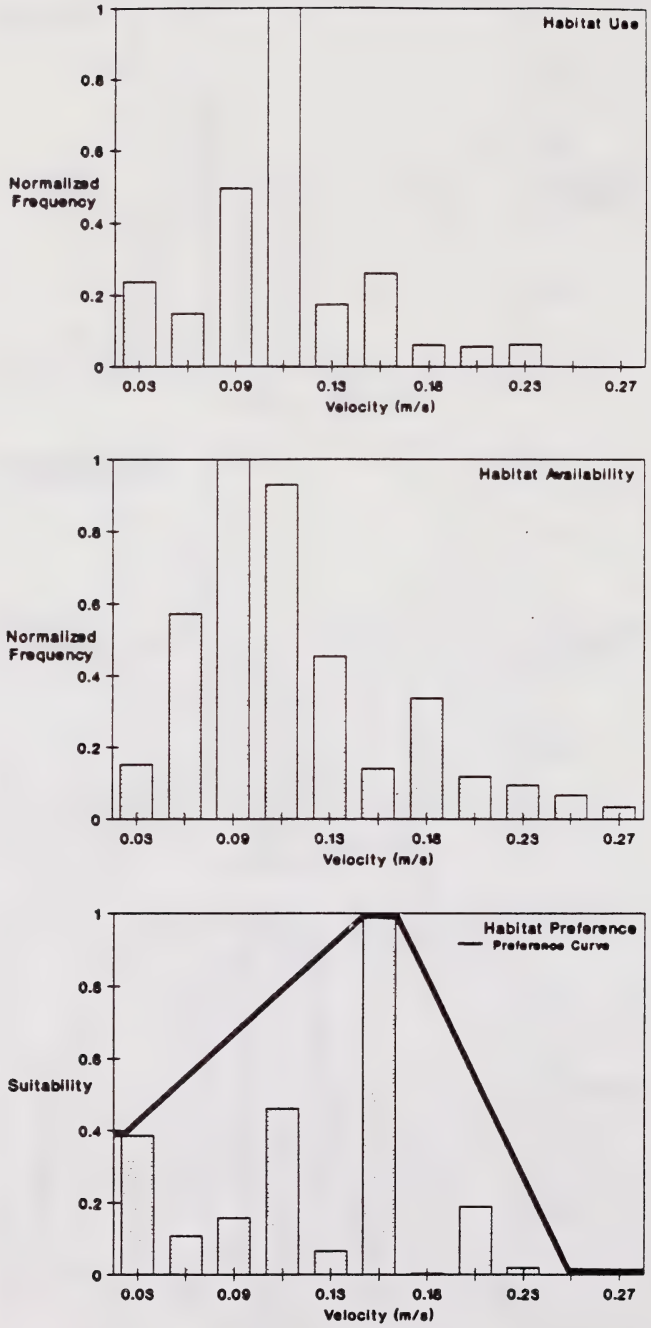



Figure IV-38. Velocity use, availability and preference for sauger adult (day) from the Oldman River.

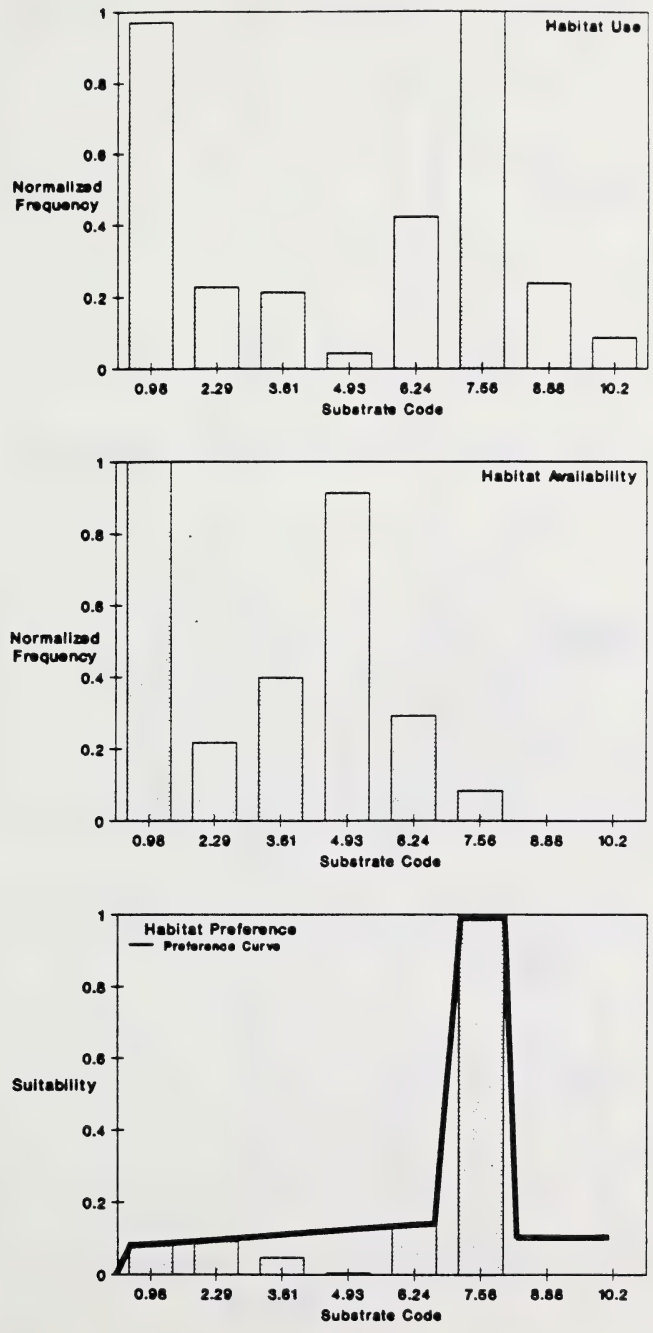



Figure IV-39. Substrate use, availability and preference for sauger adult (day) from the Oldman River.

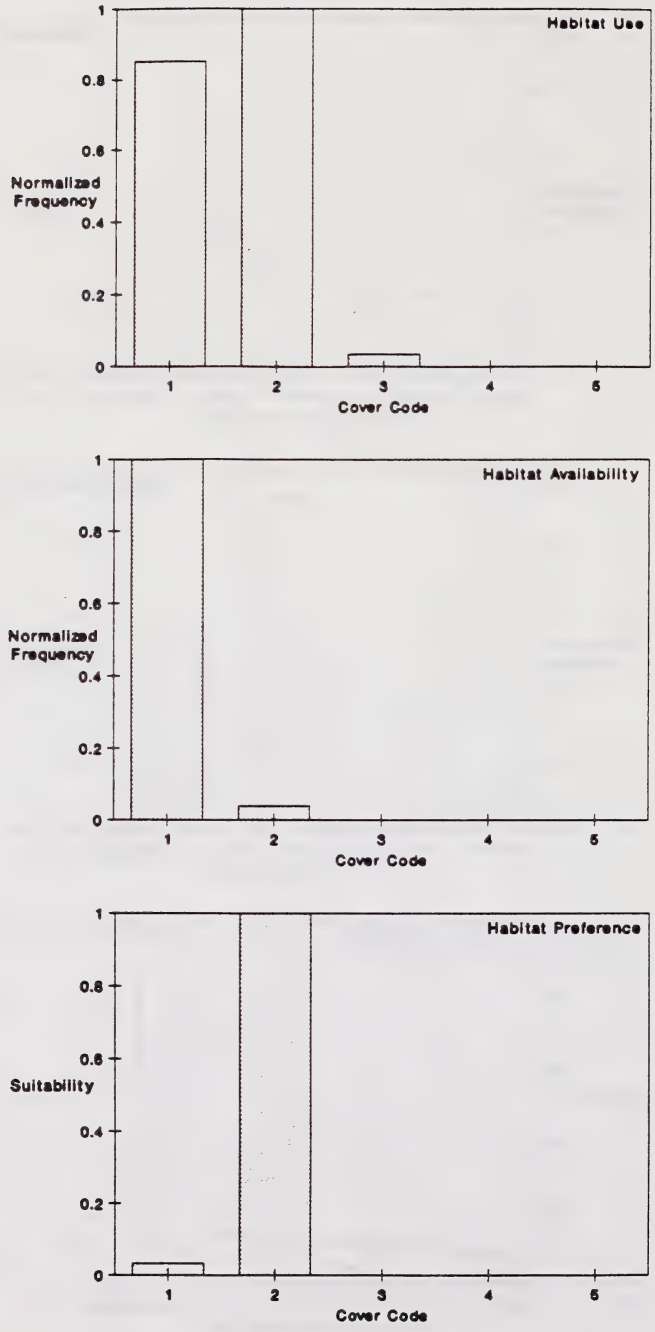



Figure IV-40. Cover use, availability and preference for sauger adult (day) from the Oldman River.

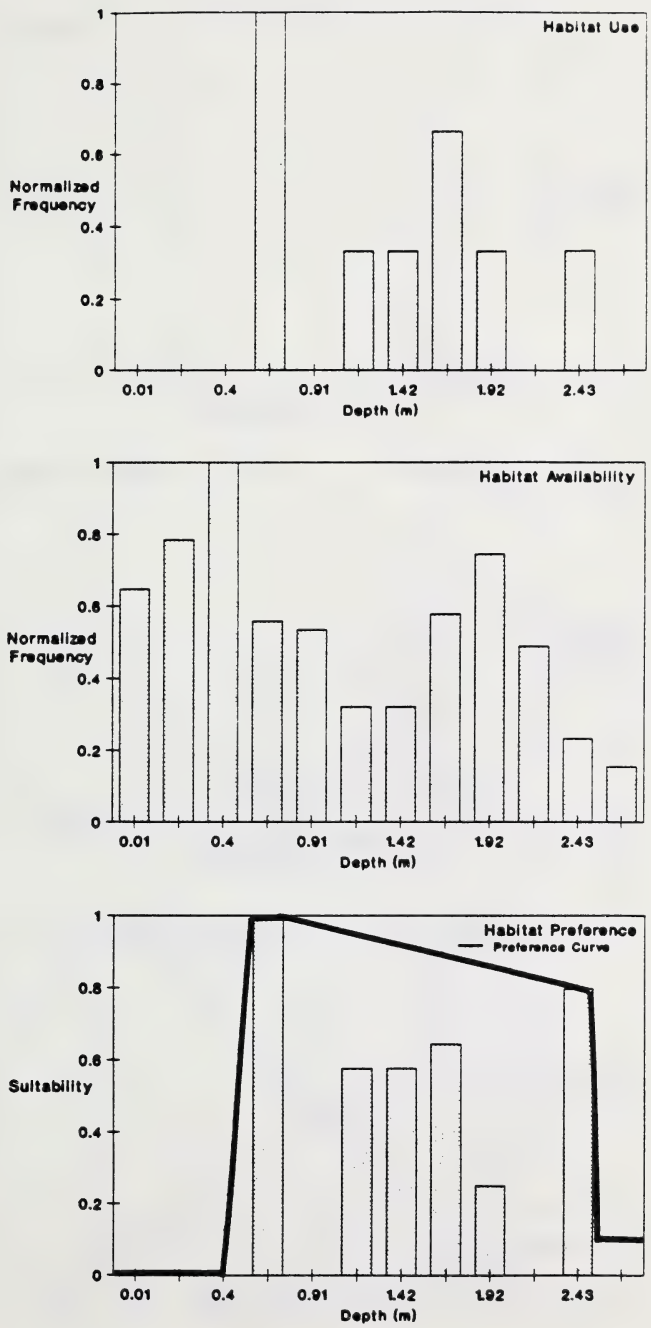



Figure IV-41. Depth use, availability and preference for sauger adult (night) from the Oldman River.

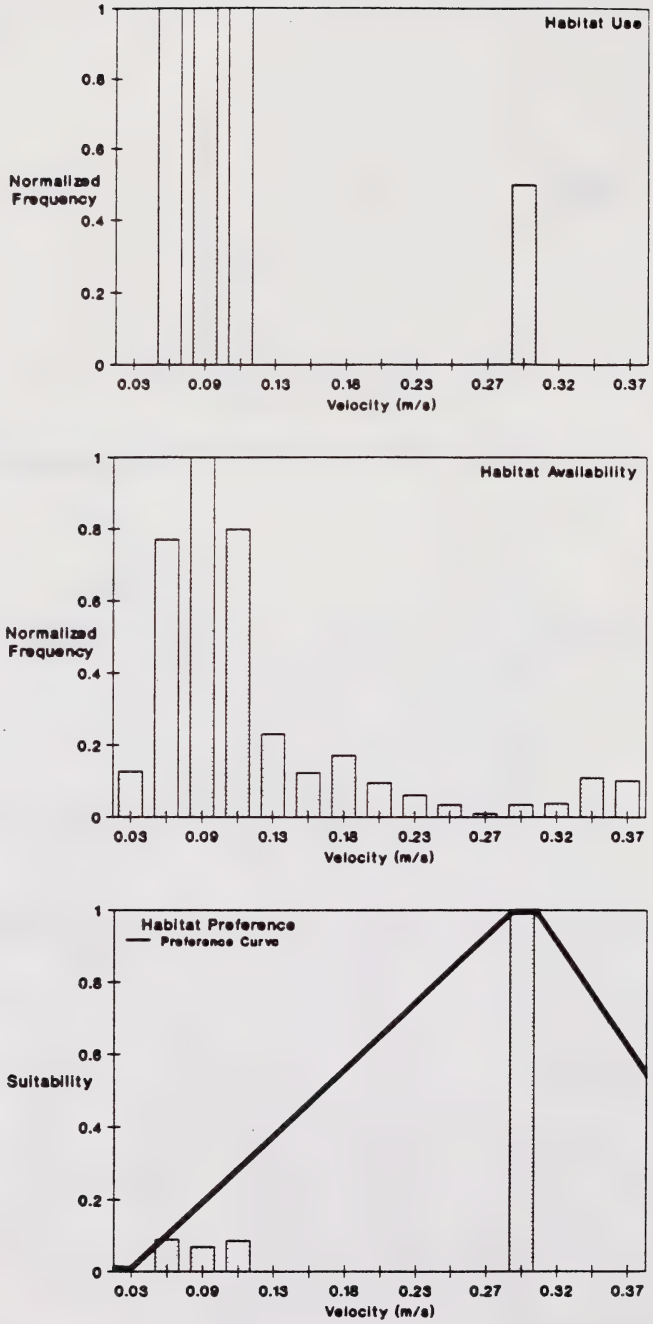



Figure IV-42. Velocity use, availability and preference for sauger adult (night) from the Oldman River.

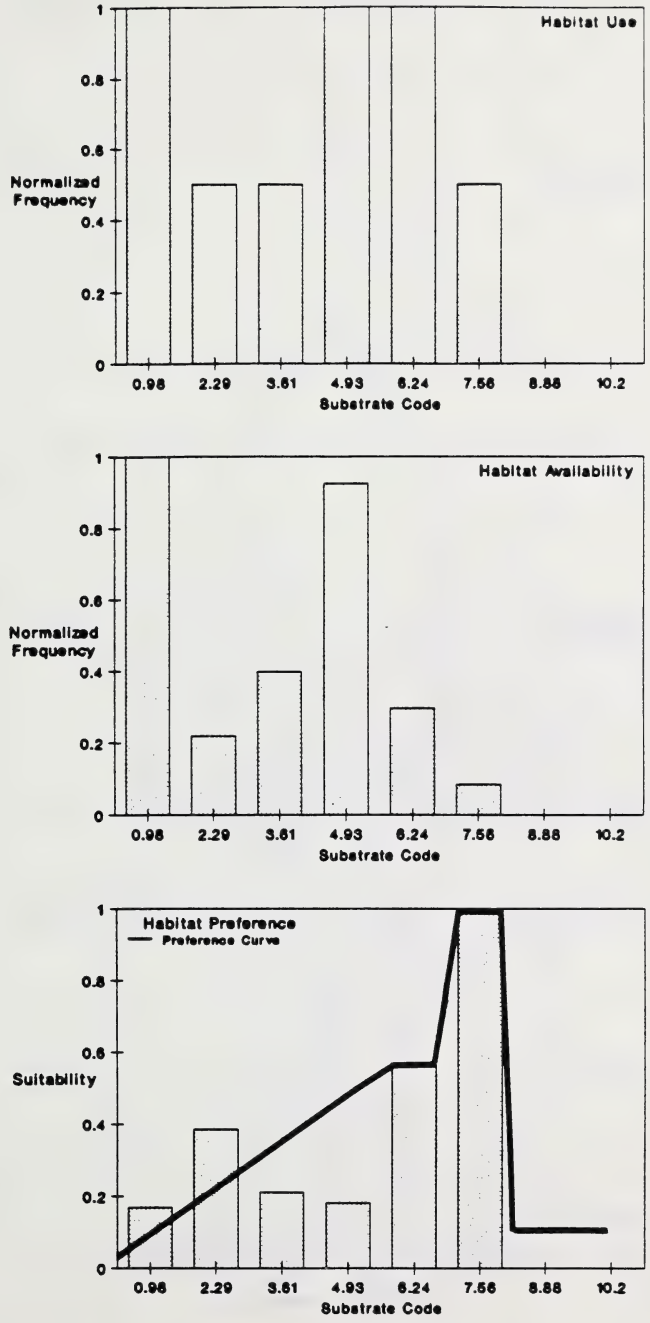



Figure IV-43. Substrate use, availability and preference for sauger adult (night) from the Oldman River.

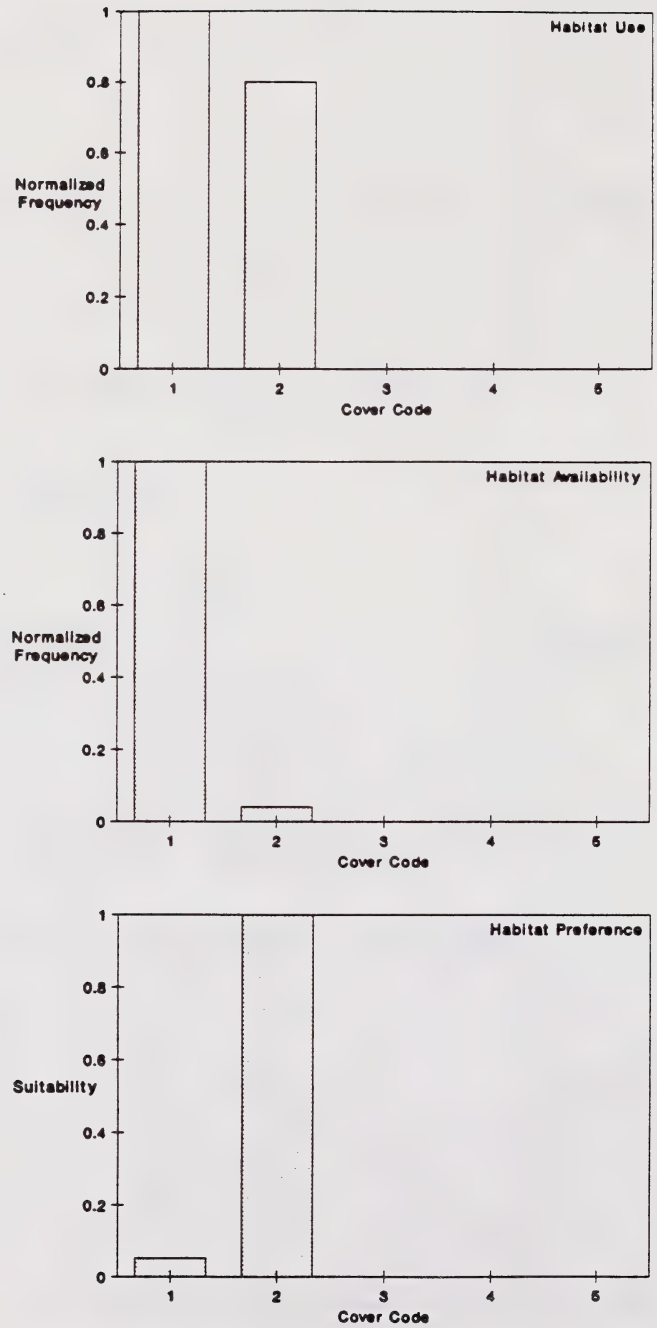



Figure IV-44. Cover use, availability and preference for sauger adult (night) from the Oldman River.

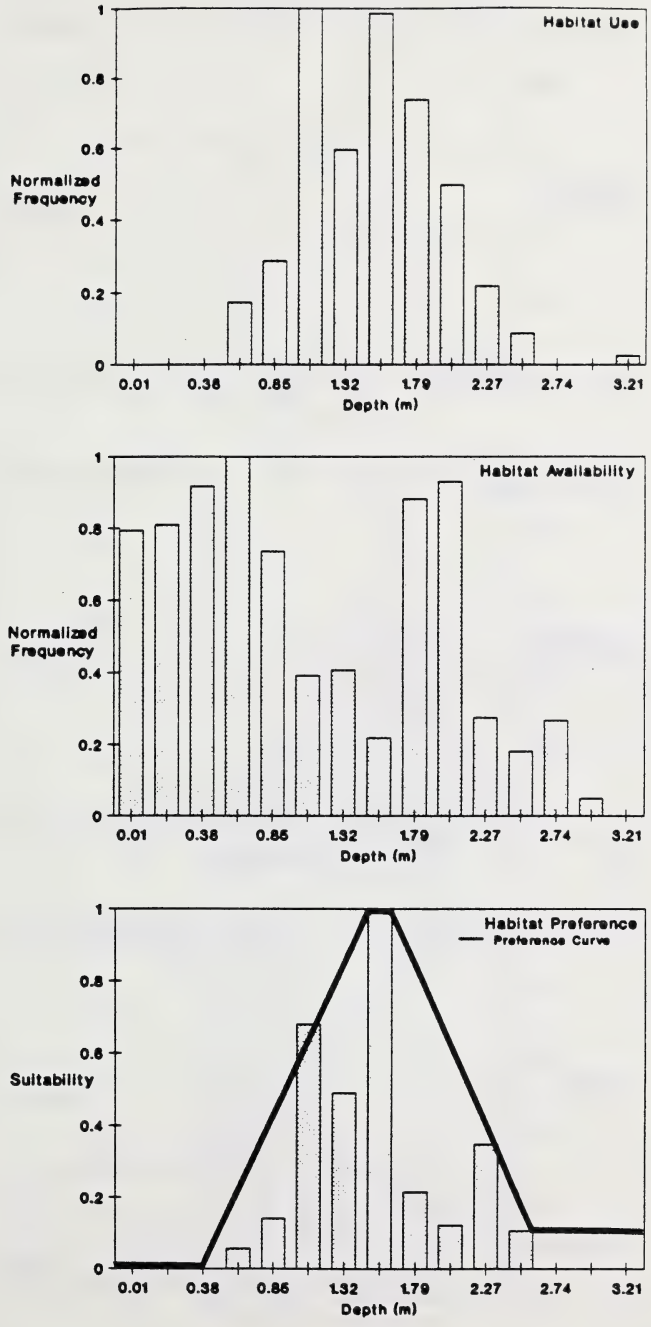



Figure IV-45. Depth use, availability and preference for walleye juvenile (day) from the Oldman River.

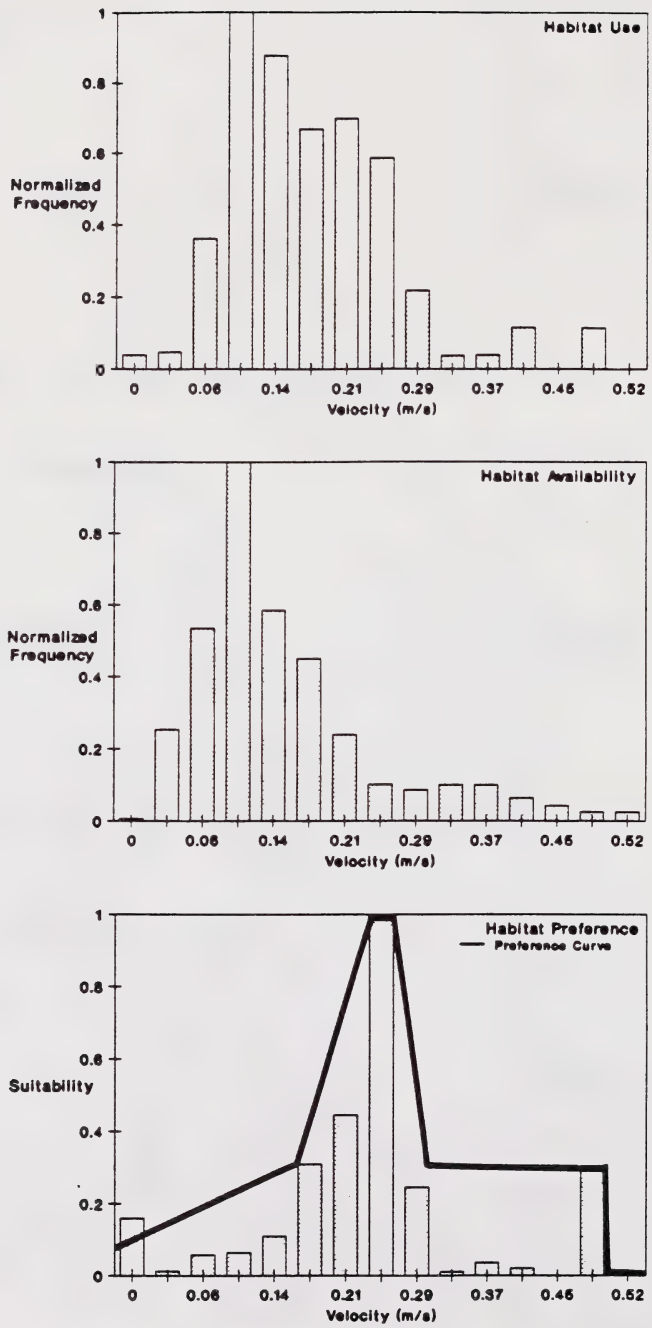



Figure IV-46. Velocity use, availability and preference for walleye juvenile (day) from the Oldman River.

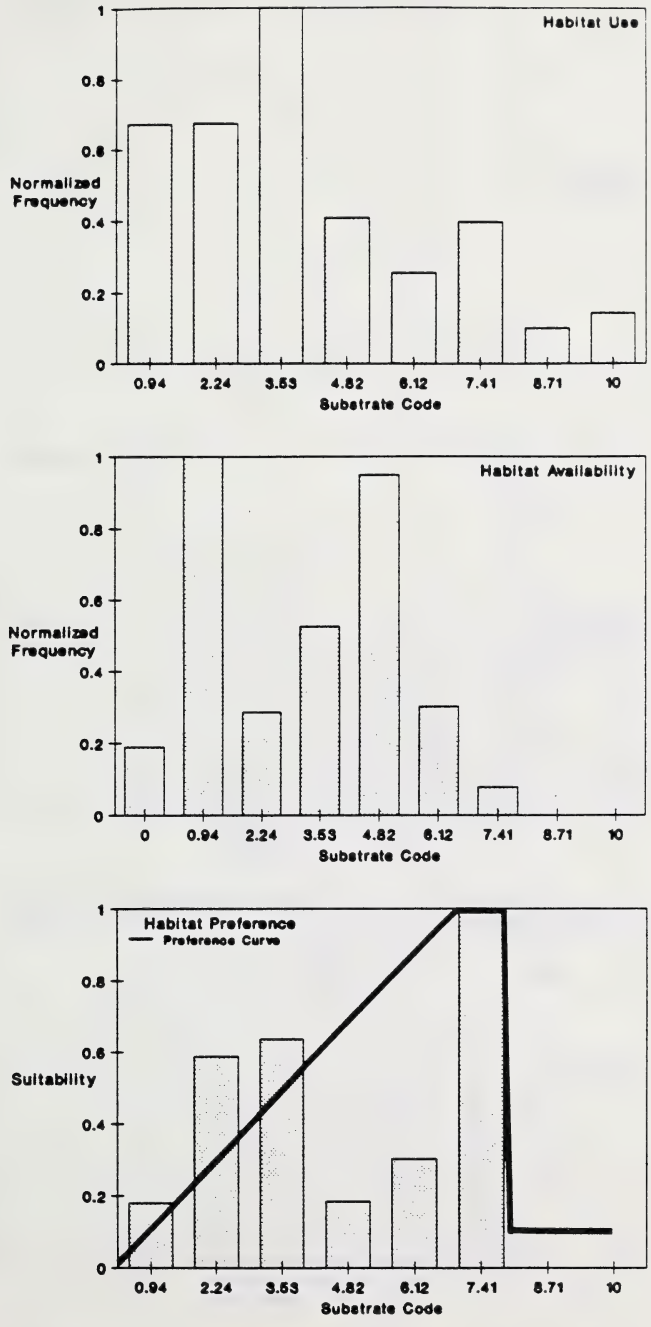



Figure IV-47. Substrate use, availability and preference for walleye juvenile (day) from the Oldman River.

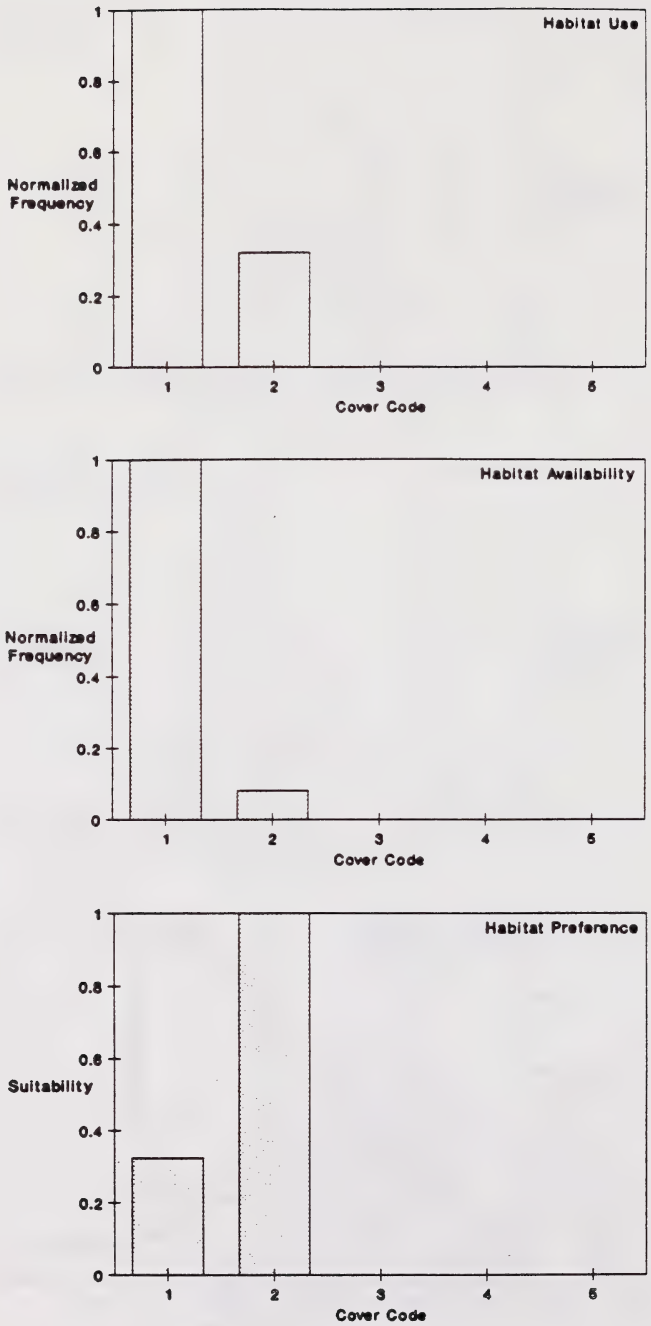



Figure IV-48. Cover use, availability and preference for walleye juvenile (day) from the Oldman River.

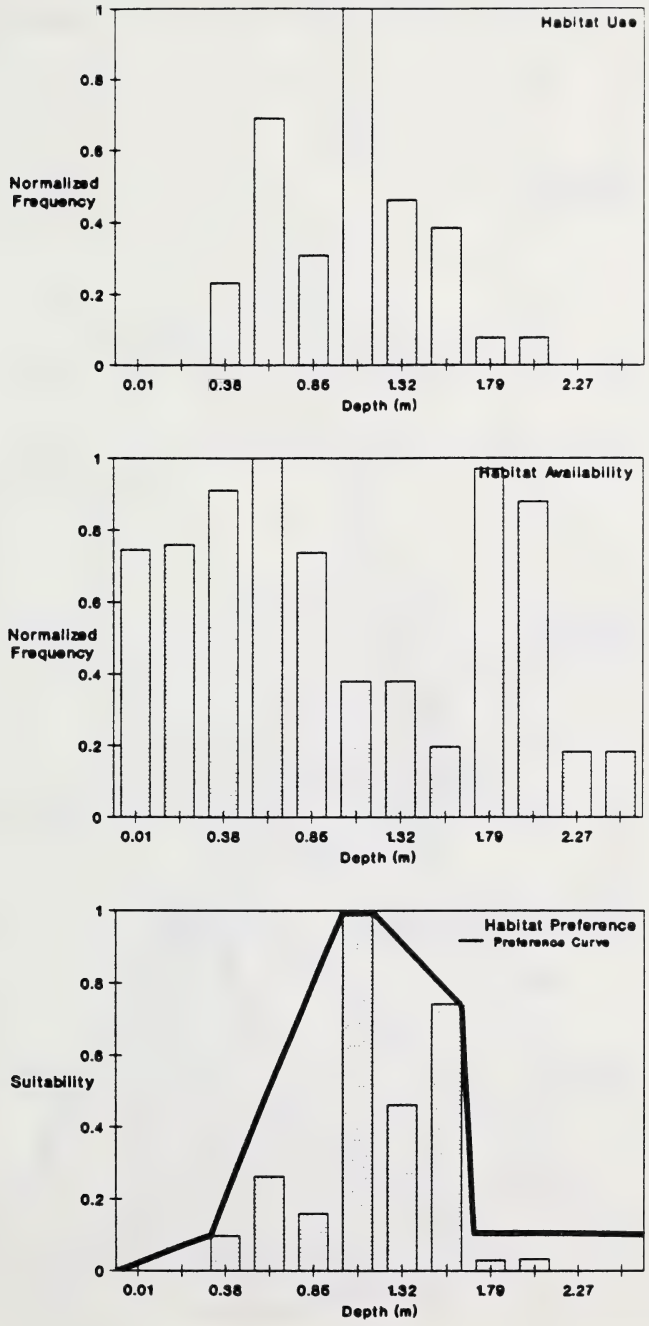



Figure IV-49. Depth use, availability and preference for walleye juvenile (night) from the Oldman River.

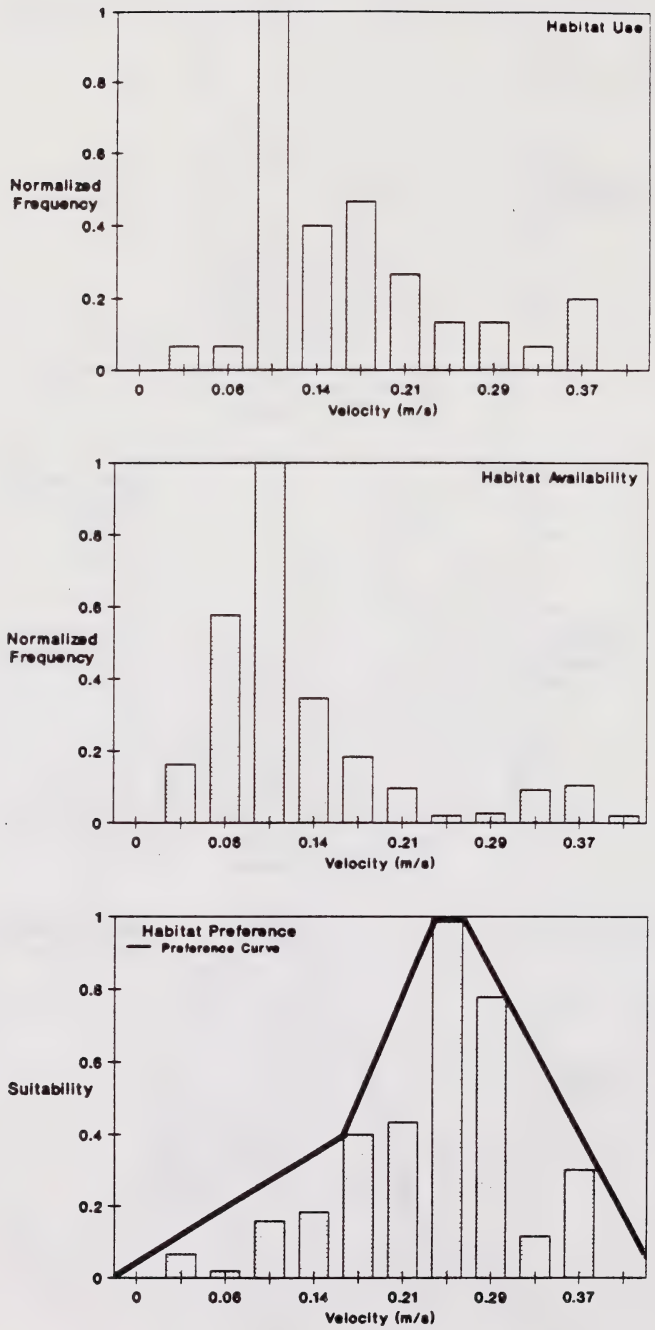



Figure IV-50. Velocity use, availability and preference for walleye juvenile (night) from the Oldman River.

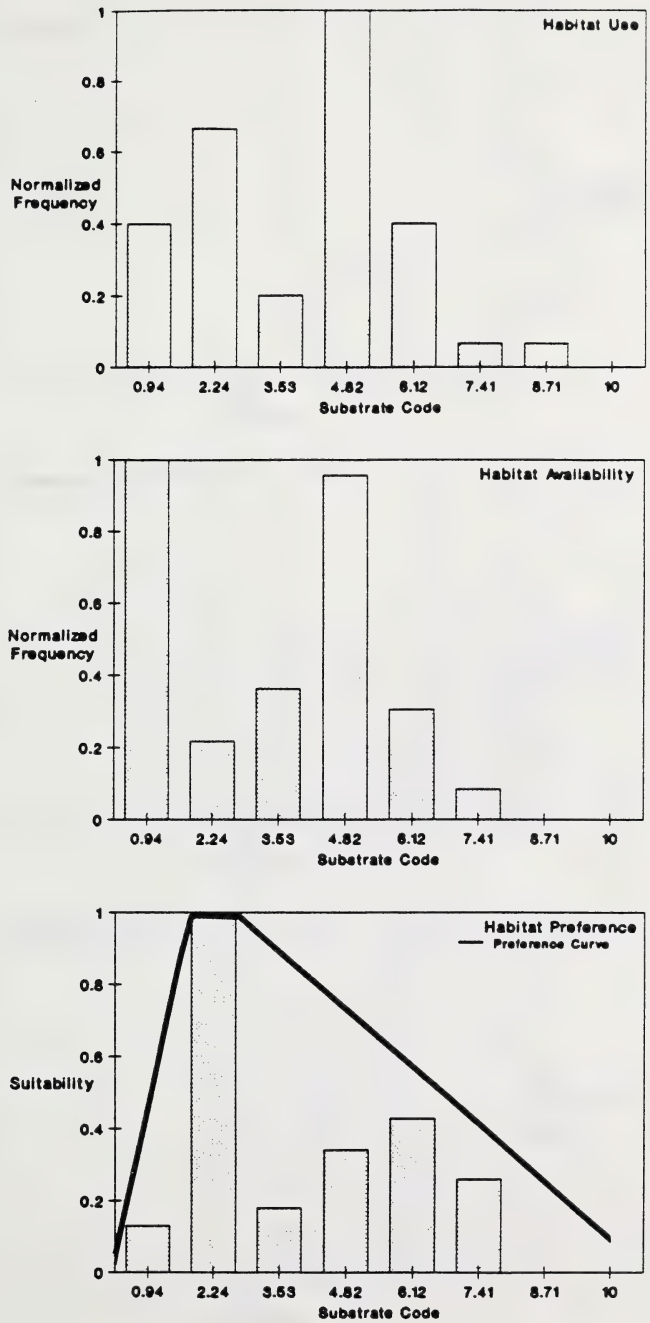



Figure IV-51. Substrate use, availability and preference for walleye juvenile (night) from the Oldman River.

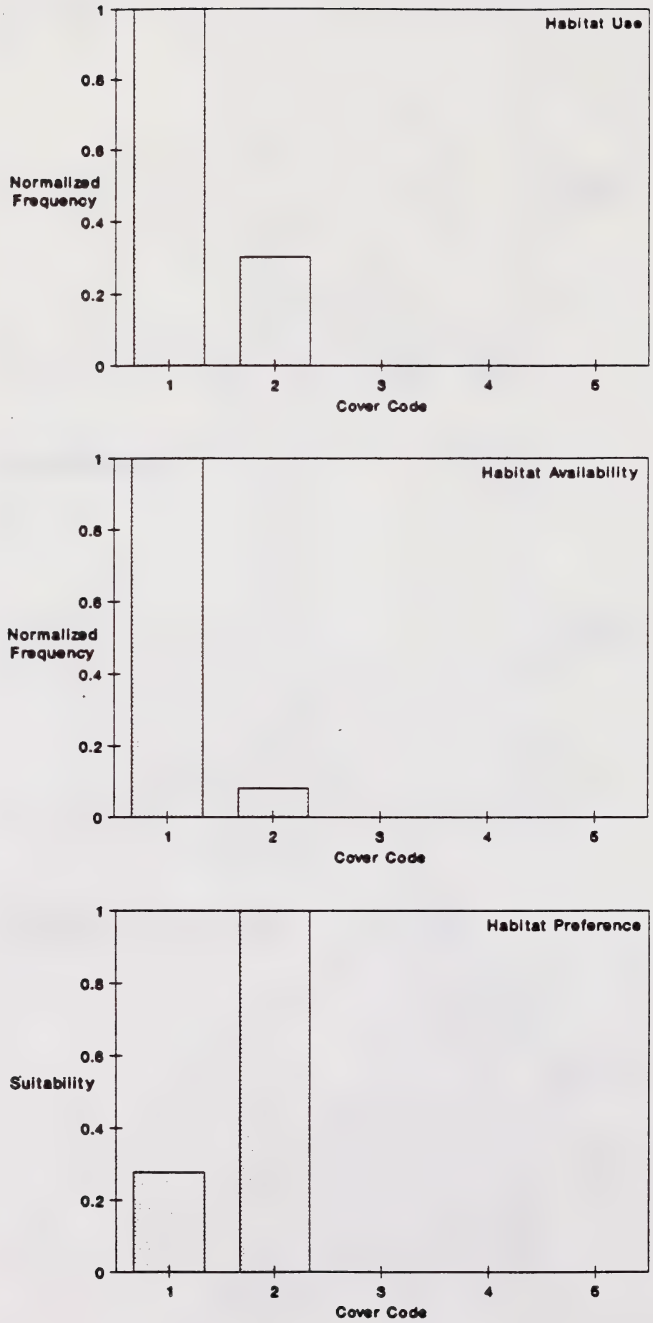



Figure IV-52. Cover use, availability and preference for walleye juvenile (night) from the Oldman River.

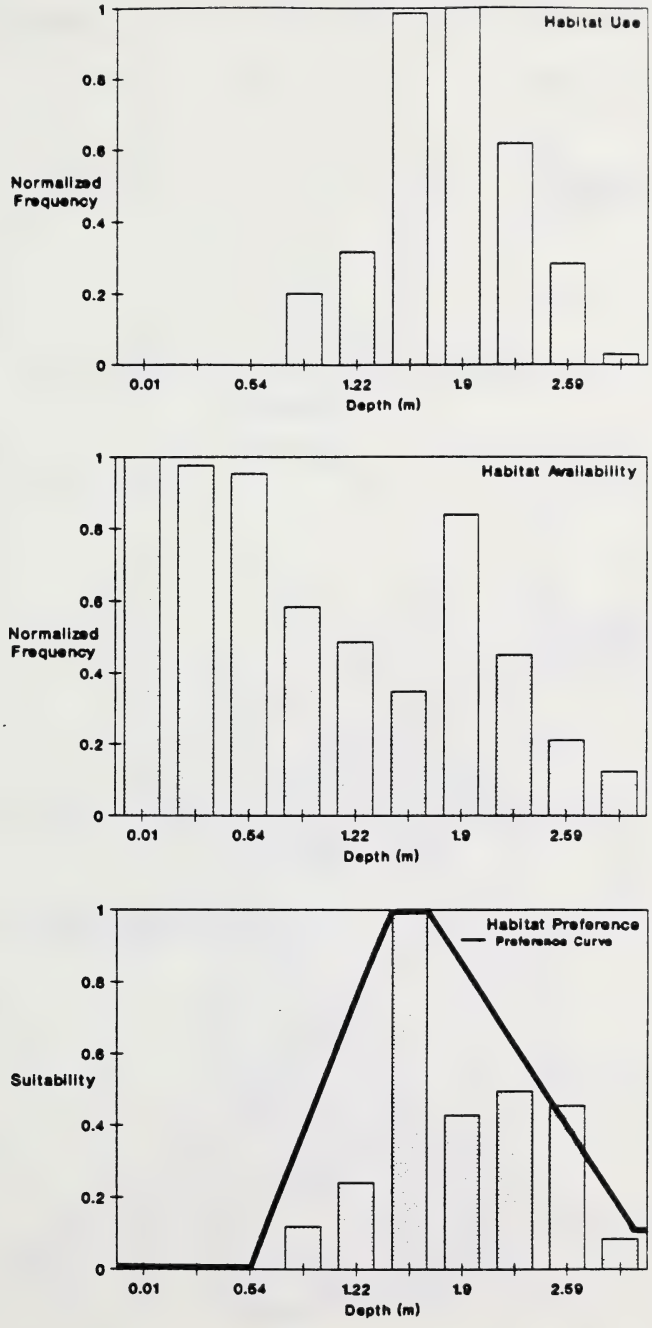



Figure IV-53. Depth use, availability and preference for walleye adult (day) from the Oldman River.

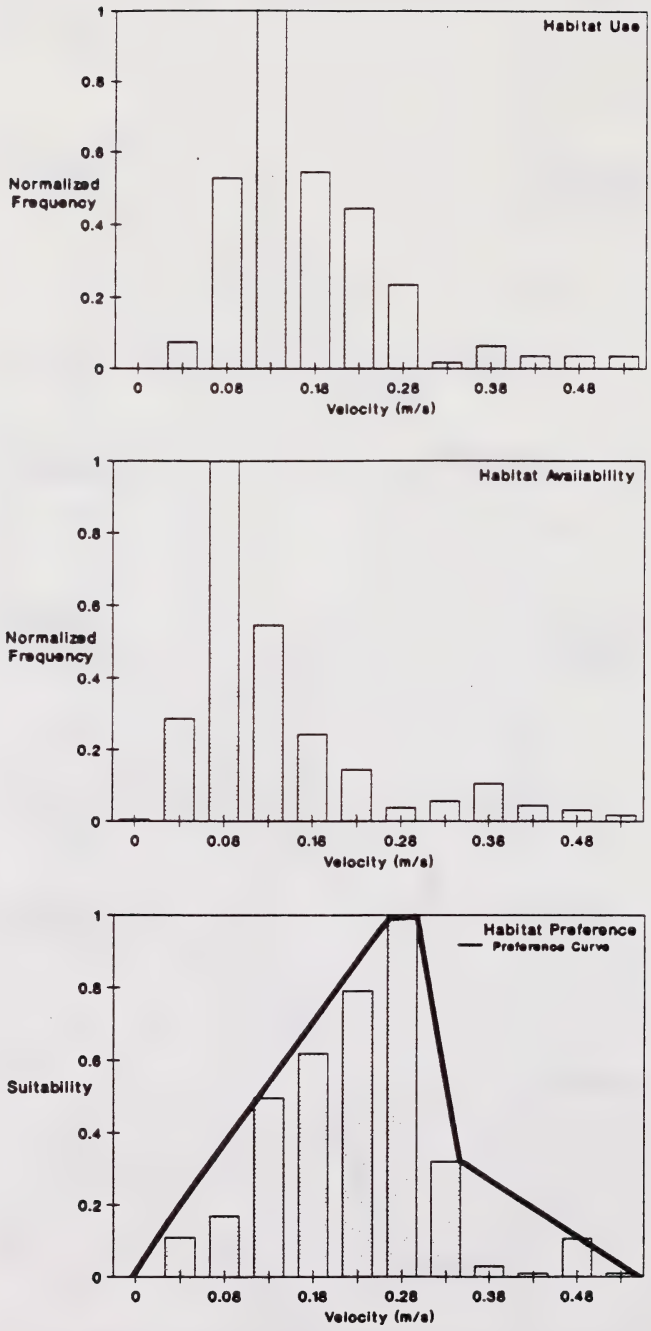



Figure IV-54. Velocity use, availability and preference for walleye adult (day) from the Oldman River.

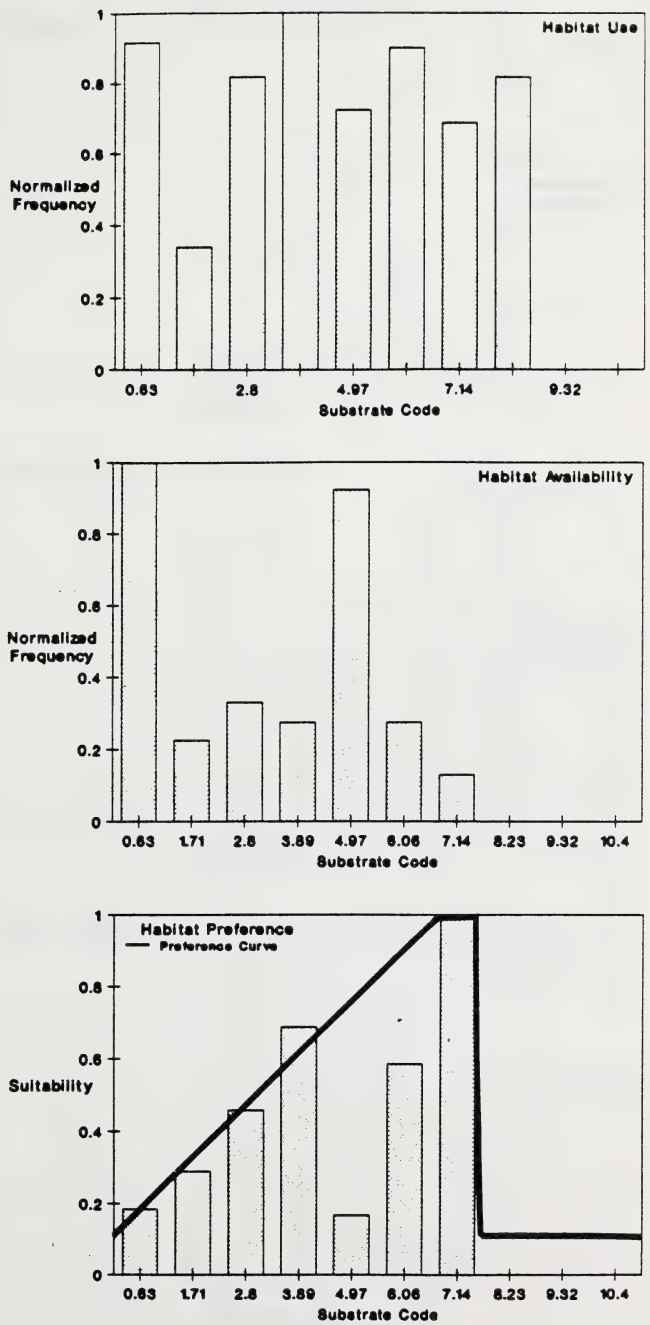



Figure IV-55. Substrate use, availability and preference for walleye adult (day) from the Oldman River.

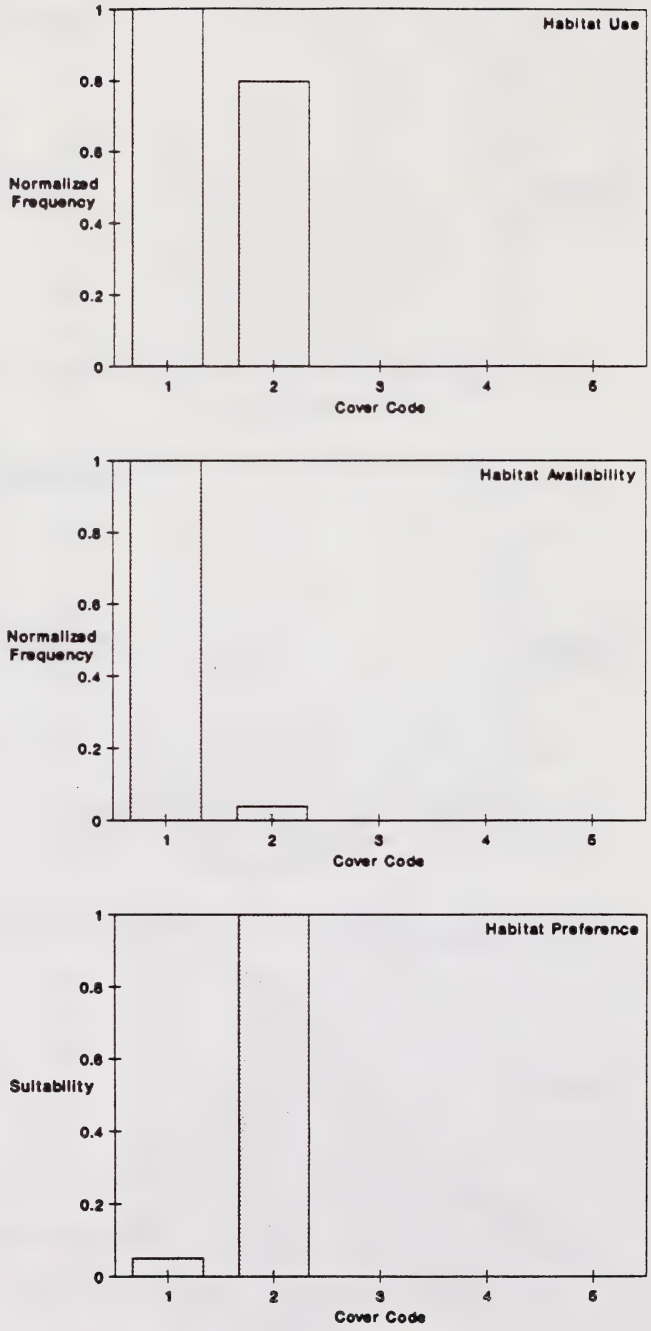



Figure IV-56. Cover use, availability and preference for walleye adult (day) from the Oldman River.

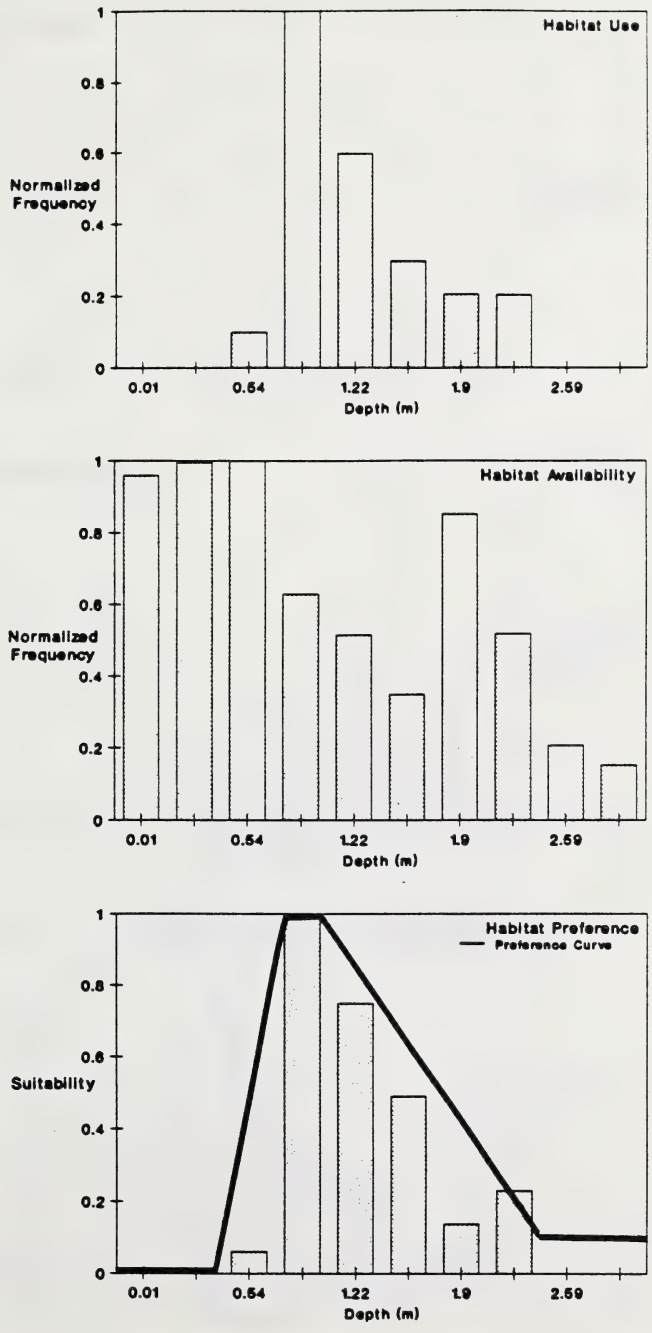



Figure IV-57. Depth use, availability and preference for walleye adult (night) from the Oldman River.

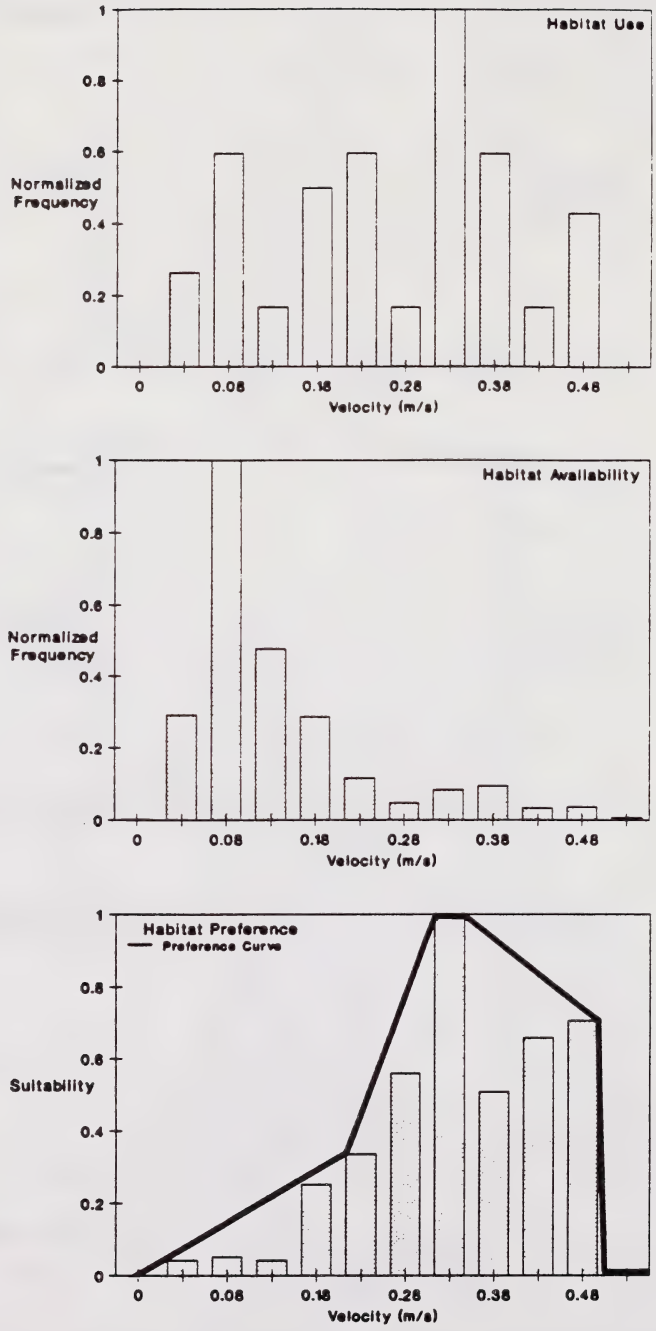



Figure IV-58. Velocity use, availability and preference for walleye adult (night) from the Oldman River.

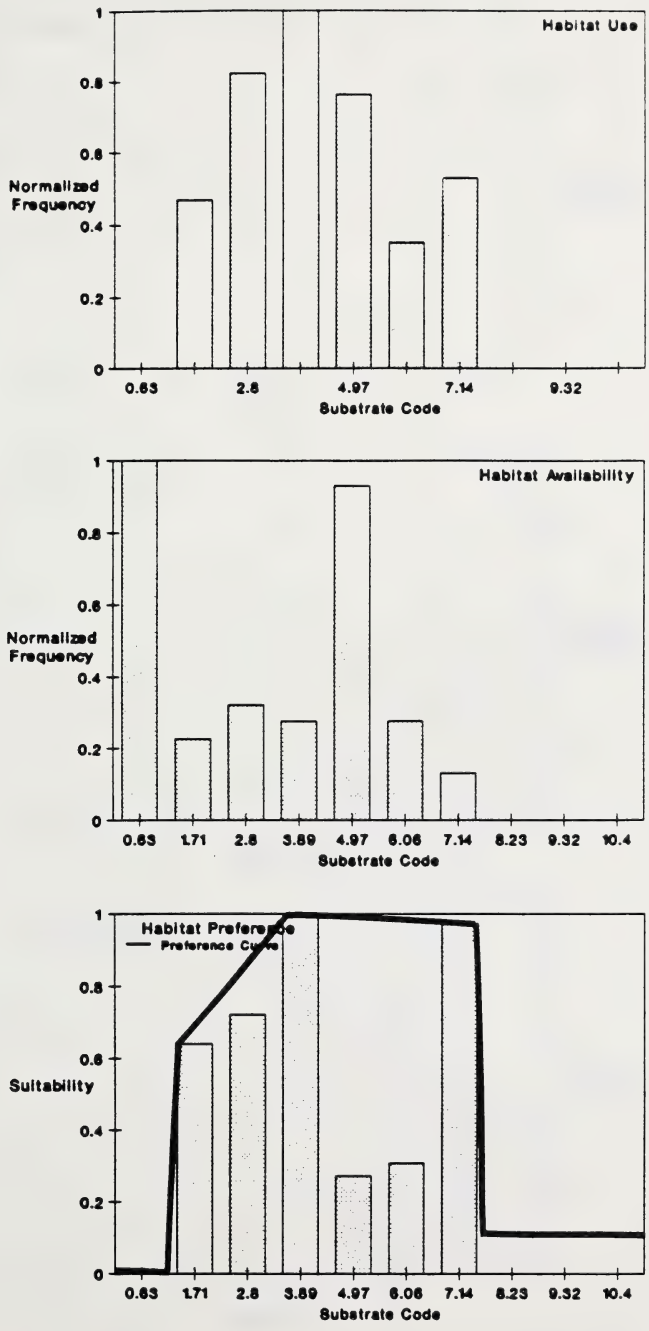



Figure IV-59. Substrate use, availability and preference for walleye adult (night) from the Oldman River.

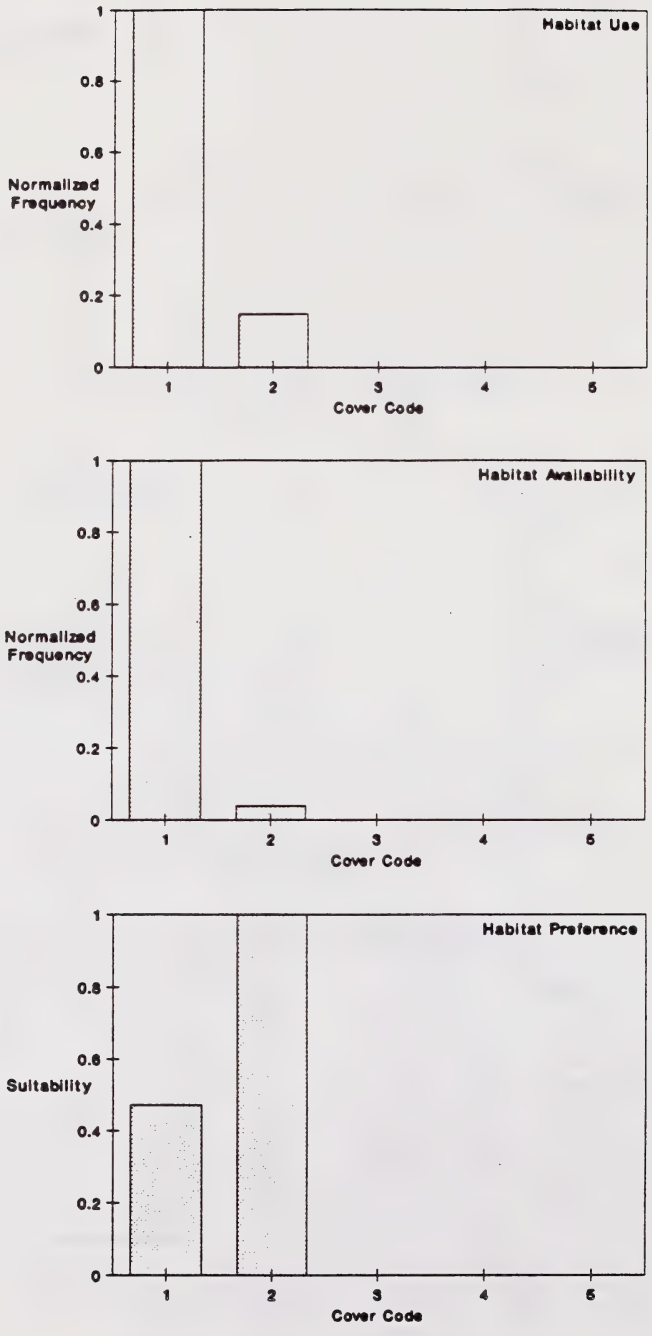



Figure IV-60. Cover use, availability and preference for walleye adult (day) from the Oldman River.



LIBRARY AND ARCHIVES CANADA
Bibliothèque et Archives Canada
3 3286 54263610 1